Physical Geography of the White Mountains, California-Nevada

By

Douglas Richard Powell

A.B. (College of the Pacific) 1941

THESIS

Submitted in partial satisfaction of the requirements for the degree of

MASTER OF ARTS

in

Geography

in the

GRADUATE DIVISION

of the

UNIVERSITY OF CALIFORNIA

Approved:

James J. Parsons

John E. Kesseli

Nello Pace

Committee in Charge

Donald Coney

MAR 29 1963

Deposited in the University Library..... Librarian

Date

a

308t
1963
58

TABLE OF CONTENTS

Page

Preface..... 1

Introduction..... 3

I. Climate..... 9

Weather Stations..... 9
Temperature..... 13
Precipitation..... 16
Types of Storms..... 18
Seasonal Distribution of Precipitation..... 27
Differences in Precipitation..... 31
Snowfall..... 35
Wind and Lee Waves..... 42
Past Climate..... 44

II. Geological Background..... 50

Lithology..... 50
Structure..... 55
Mineral Resources..... 56

III. Topography..... 61

The Area in General..... 61
The Mountains and Valleys..... 61
Drainage..... 76
Soils..... 81

Geomorphic Processes..... 86
Summary..... 86
Snowdrifts, Nivation, and Solifluction..... 89
Glaciation..... 92

IV. Topographic Regions..... 103

Northeast Volcanic Area..... 103
Boundary Peak-Montgomery Peak Area..... 106
Summit Upland..... 108
West Slope..... 116
Northeast Owens Valley and Owens Valley..... 118
East Slope..... 120
Fish Lake Valley..... 124
Southeast Slope..... 126
Deep Springs Valley..... 129

TABLE OF CONTENTS (continued)

Page

V. Biota..... 132

Desert Shrub Zone..... 133
Pinyon-Juniper Zone..... 139
Upper Pine Zone..... 145
Alpine Zone..... 153
Interzonal Species..... 156
Introduced Species..... 159

Conclusion..... 162

Bibliography..... 165

LIST OF FIGURES

Number		Page
1.	Index map of the White Mountain area	4
2.	Map of boundaries and place names of the White Mountain area	5
3.	Location, elevation, and years of record for weather stations in and near the White Mountains	10
4.	Surface weather map for Feb. 9, 1962	20
5.	Winter storm front approaching White Mountains from Sierra Nevada.	21
6.	Surface weather map for May 14, 1962	22
7.	500 Millibar constant pressure chart for July 23, 1955	25
8.	Thunderstorm over White Mountain Peak, July 20, 1955	26
9.	Thunderstorm moving eastward from crest of Sierra Nevada to White Mountains	26
10.	View from White Mountain Peak of snowstorm brought by northeast wind	28
11.	Blowing snow on Pellisier Flats	29
12.	Cumulo-nimbus buildup over summit north of White Mountain Peak	34
13.	Cumulo-nimbus buildup over summit upland south of White Mountain Peak	34
14.	Mid-winter snow mantle on White Mountain Peak	37
15.	Snow cornices along east edge of summit upland	39
16.	Snowdrifts on northwest slope of Montgomery Peak	39
17.	Telephoto view of summit upland from Montgomery Peak, May 26, 1954	40
18.	Telephoto view of summit upland from Montgomery Peak, June 18, 1952	40
19.	Snowcover in Northeast Owens Valley	41
20.	Generalized diagram of Sierra Wave	45
21.	Sierra Wave clouds over Owens Valley	46
22.	Lee wave clouds on the east side of the White Mountains	46
23.	Geologic map of the White Mountain area	51
24.	Telephoto view of White Mountain Peak from Mount Barcroft	53
25.	George Grieve concentrating gold	58
26.	Open cut workings of the B&B mercury mine	58
27.	Chief mineral deposits discovered in the White Mountains	60
28.	Sierra Nevada from Black Mountain	62
29.	View west from White Mountain Peak	64
30.	View east from White Mountain Peak	64
31.	View from Boundary Peak	65
32.	Northern crest of the White Mountains from Pellisier Flats south to White Mountain Peak	66
33.	White Mountain Peak from the west	67
34.	White Mountain Peak from the east	67
35.	Looking north along White Mountain crest from east shoulder of Sheep Mountain	69
36.	West side of White Mountain Range from Adobe Valley	70
37.	View north along White Mountain crest from Black Mountain	70
38.	Generalized profiles of west to east slopes of the White Mountains	71
39.	Dunes in Fish Lake Valley	75
40.	Owens River near Laws	75

LIST OF FIGURES (continued)

Number		Page
41.	Past drainage patterns in the vicinity of the White Mountains	80
42.	Map of land classification for agricultural development in northern Fish Lake Valley	83
43.	South McNally Canal in Owens Valley	84
44.	Abandoned homestead in central Fish Lake Valley	84
45.	Mass movement by rockfall, rock creep, and solifluction at the head of Middle Creek	88
46.	Debris flow of July 26, 1952, on Lone Tree Creek fan	88
47.	Sunpits on Pellisier Flats	91
48.	Snowdrift at east side of summit upland	91
49.	Runoff channels from high elevation snowdrift	93
50.	Glacially eroded canyon of the north branch of the North Fork of Perry Aiken Creek	93
51.	Map of morainal deposits on the east side of the White Mountains.	95
52.	Glacial substage in the North Fork of Chiatovich Creek	96
53.	Rock glaciers and pro-talus ridges at the head of the South Fork of Chiatovich Creek	98
54.	Moraines in the North Fork of Chiatovich Creek	99
55.	Moraines in the north branch of the North Fork of Perry Aiken Creek	99
56.	Map of the topographic regions of the White Mountain area	104
57.	View southwest from Mustang Mountain	107
58.	Montgomery Peak from the north end of Pellisier Flats	107
59.	Northern summit upland from ridge north of White Mountain Peak	110
60.	South Fork of Birch Creek and Cabin Creek from the north	110
61.	View east along Chiatovich Flat	112
62.	Outcrops of granodiorite on summit upland	112
63.	South summit upland from the shoulder of Sheep Mountain	113
64.	View of west slope of White Mountains	117
65.	Southwest slope of White Mountains and Owens Valley from Black Mountain	117
66.	Cirque of North Fork of Chiatovich Creek from Pellisier Flats	121
67.	Debris flow in Leidy Creek	123
68.	Recent faulting at the mouth of Perry Aiken Creek	123
69.	Cottonwood Basin from the west	127
70.	Granite pinnacle in Cottonwood Basin	128
71.	Deep Springs Valley from the southwest	130
72.	General view of desert shrub zone	135
73.	Stanleya elata, a showy perennial of the desert shrub zone	138
74.	Greasewood growing on alkaline lakebed in Fish Lake Valley	138
75.	Autumn coloring in Owens Valley	140
76.	Meadow in the pinyon-juniper zone	144
77.	Mountain mahogany on south-facing ridge	144
78.	Bristlecone pine forest on Reed dolomite	147
79.	Pine Alpha, the first bristlecone pine to be dated as over 4,000 years old	147
80.	The Patriarch, largest known bristlecone pine tree	148

LIST OF FIGURES (continued)

Number Page

81. Limber pine forest..... 149
82. Lodgepole pine on north-facing slope of Cabin Creek..... 149
83. Dwarf limber pine at timberline..... 151
84. Prostrate limber pine near timberline..... 151
85. Woodland and forest areas of the White Mountains..... 152
86. Hulsea algida, a showy herb of the alpine zone..... 155
87. Trifolium monoense, a common herb of the alpine zone and upper pine zone..... 155
88. General view of alpine zone..... 157
89. Bighorn ram on Pellisier Flats..... 158

LIST OF TABLES

Number Page

I. Average monthly and annual temperatures for stations in and near the White Mountains..... 11

II. Average monthly and annual precipitation for stations in and near the White Mountains..... 12

III. Seasonal totals of precipitation at White Mountain I and White Mountain II..... 17

IV. Percentage of precipitation by seasons..... 30

V. Average monthly and seasonal snowfall at White Mountain I and White Mountain II..... 36

VI. Characteristic plants and animals of the desert shrub zone..... 134

VII. Characteristic plants and mammals of the pinyon-juniper zone.... 141

VIII. Characteristic plants and mammals of the upper pine zone..... 146

IX. Characteristic plants and animals of the alpine zone..... 154

PREFACE

In July, 1937, along with 11 other boys and a leader, I climbed Mount Sill, a 14,000' peak in the Sierra Nevada of California. From the summit I looked eastward and was much surprised to see that across the 10,000'-deep trough of Owens Valley was another mountain range, brown and desertlike at its base, but covered with snow at its summit and as high as the Sierra Nevada. The leader explained that this was the White Mountains, a little known desert range along the California-Nevada border. From Mount Sill on that July day the White Mountains looked most alluring and I resolved to go into those mountains sometime and see what was there. After the end of World War II in 1945 I did go into those mountains and have been returning ever since. At first, the mission was to climb the highest summit (14,246'). Then came an ever growing interest in what was there--the weather and climate, the geology, the topography, the flora and fauna of the White Mountain Range and its surrounding valleys. The following 169 pages are a result of that interest.

I am deeply grateful for the friendship, conversation, encouragement, hospitality, and generous help of numerous people in the White Mountain area and at the University of California, especially to the following:

In Owens Valley: Pat and Dave Wiltsie, Ashee and Elliott Earll, Jim Nicklaus, Phil Pister, Al Noren.

In Fish Lake Valley: Roberta and Walter Dunnigan, Lidabell and Sam Wright, Wayne Rupp, Loy Thomasson, Carl Durr.

In Deep Springs Valley: Ed Loomis, the sometimes exasperating, but always stimulating, student body of Deep Springs College.

At the White Mountain Research Station, in the field and at Berkeley, California: Dr. Nello Pace, Director; Dr. Ralph Kellogg, Dr. Ray Hock, Elmer Bulow, Joe Wentworth, Dave Mathias, Bill Roche, and especially Operations Manager Paul Manis.

At the University of California:

Dr. John E. Kesseli, for awakening and sustaining my interest in physical geography and for his Job-like patience.

Dr. James J. Parsons, for many helpful suggestions in the writing of the dissertation and for a similar patience.

Lucille McClish, for typing the manuscript on short notice amidst countless other duties.

INTRODUCTION

The highest of the many Great Basin ranges that are arranged en echelon between the Sierra Nevada and the Wasatch are the White Mountains, situated on the California-Nevada border 225 miles due east of San Francisco (Fig. 1, p. 4). They reach an elevation of 14,246' at White Mountain Peak; altitude of the surrounding lowlands is 4,000' to 5,000'. It is an area of extreme aridity in its lowest reaches, of semi-aridity at its summits, with average annual precipitation of 4" to 20", most of which above 7,000' falls as snow. It is a region of great climatic, geologic, topographic, and biologic diversity, one in which the author has spent many seasons, as student and admirer of its geographic charm and complexity. This dissertation is a description of the physical geography--climate, geology, topography, and biota--of the White Mountains and their adjacent lowlands.

The boundaries of the study area are determined by its chief topographic feature, the mountains (Fig. 2, p. 5). The entire White Mountain Range is included and those valleys or portions thereof that receive drainage from it. Between Montgomery Pass (7,122') at the north end of the Range and Westgard Pass (7,313') near its southern extremity, is a distance of 50 miles. The west and east margins of the Range are clearly defined fault zones.

Bordering the mountains on the west is a long, narrow, flat-floored valley, a part of the Owens River drainage. In its southern third flows the Owens River, and there the river is taken as the southwestern boundary of the area. West of the river, the drainage is from the Sierra Nevada. The northern two-thirds of this bordering valley north of the city of Bishop has no perennial streams nor any generally accepted name.

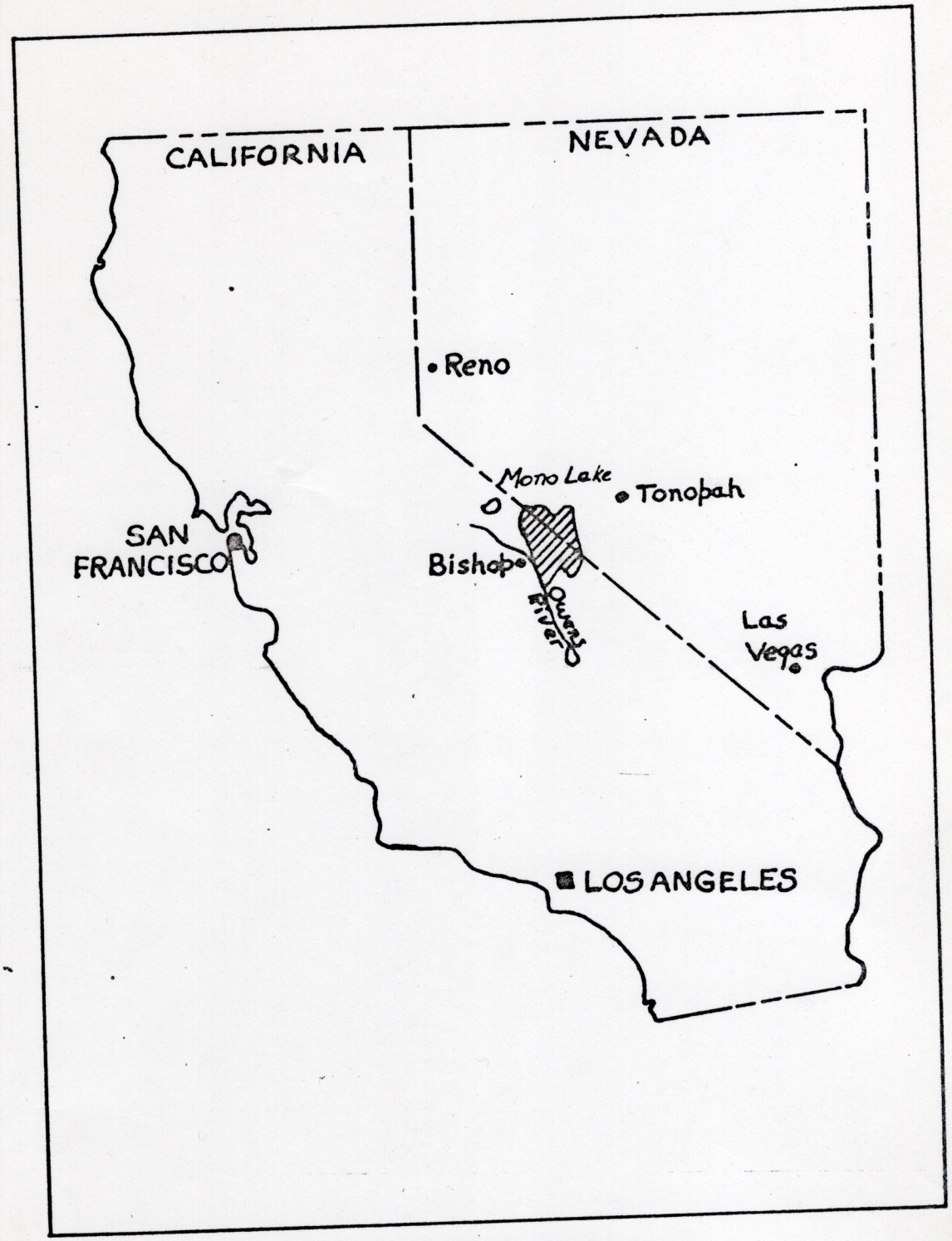

Fig. 1. Index map of the White Mountain area.

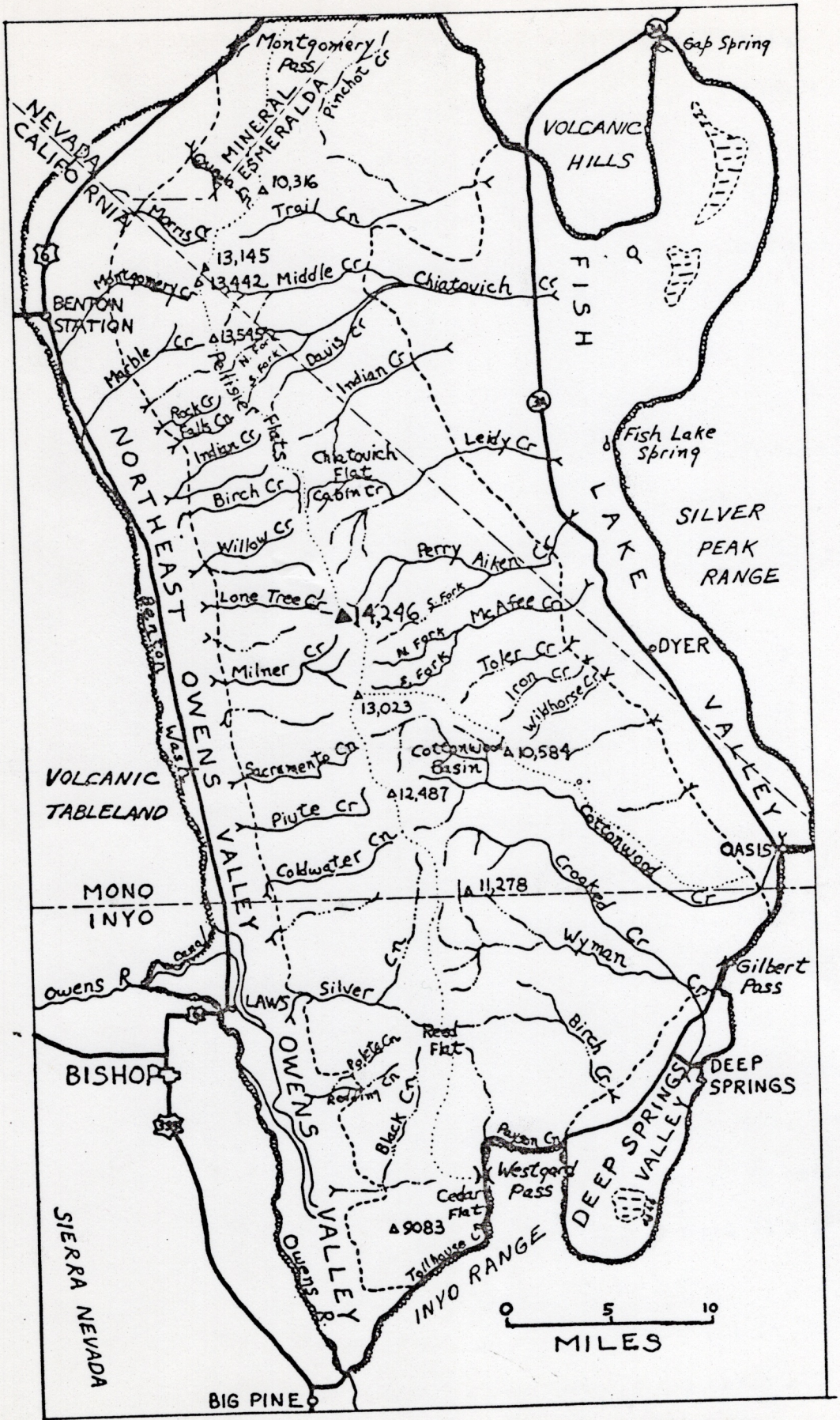

Fig. 2. Map of boundaries and place names of the White Mountain area.

Segments of it, separated by extensions of alluvial fans from the White Mountains, are called Chalfant Valley, Hammil Valley, and Benton Valley from south to north. In this study the entire valley from Owens River to Montgomery Pass will be called Northeast Owens Valley, an awkward, but geographically descriptive term. Other possibilities such as Upper Owens Valley or Northern Owens Valley would lead to confusion with the upper and northern portion of Owens River, which lies to the west. The intermittent axial drainage channel of Northeast Owens Valley, commonly called Benton Wash, lies along the valley's west margin, which is marked by steep-sided, en echelon lava flows. Thus north from the bend of the Owens River the boundary of the area follows an irrigation canal (North McNally Ditch) to its junction with Benton Wash, and along the wash to Montgomery Pass.

The east slope of the White Mountains is bordered by Fish Lake Valley. The sinuous eastern margin of this valley, from which rises the Silver Peak Range (elevation 9,500'), serves as the eastern boundary of the area.

There are no distinct topographic demarcations on the north and south other than Montgomery Pass and Westgard Pass, so boundary lines are drawn somewhat arbitrarily. In the north the 38th Parallel is followed across an area of jumbled basalt flows to an unnumbered Nevada highway connecting Fish Lake Valley with U.S. Highway #6. This highway separates the northeast slope of the White Mountains from the Volcanic Hills, and is followed to Fish Lake Valley, which is included within the study area. From this point the southern tip of the Volcanic Hills serves as a distinct boundary to Gap Spring at the northeast end of the valley.

On the south the arbitrary boundary of the White Mountain Range is an unnumbered California highway from its crossing of the Owens River just east of the town of Big Pine northeastward to Tollhouse Canyon to Westgard

Pass, then down Payson Canyon to Deep Springs Valley. The entire floor of this valley is included within the study area, as practically all of the drainage into it is from the White Mountains. The remainder of the boundary is the same highway from Deep Springs Valley over Gilbert Pass to Oasis in Fish Lake Valley and northward along the eastern edge of this valley to the Volcanic Hills. The southernmost tip of Fish Lake Valley, which receives drainage from Palmetto Wash, the Sylvania Mountains, and the Last Chance Range, is omitted.

The area, some 60 miles long with a maximum width of 32 miles, is very sparsely populated. Laws, Benton Station, and Deep Springs, the site of a private junior college, are small desert communities, each with fewer than 150 people. Dyer, Fish Lake Valley, is a post office, Oasis a ranch. The only towns of any size in the vicinity are west of the Owens River. Bishop, the largest settlement in the entire Owens Valley, had a population of close to 4,000 in 1960; Big Pine, 15 miles to the south, had 1,000.

Many observers, from the time of J.D. Whitney in 1865 down to the present, have noted that the White Mountains and the Inyo Range, which extends southward of Westgard Pass for 70 miles, are geologically and topographically one range. However, historical nomenclature has always divided this one range into the two sections. There have been some attempts in the literature to call the White Mountains the "Northern Inyo Range." This term has the merit of distinctiveness. There are other White Mountains, notably in Arizona and New Hampshire. But it is unwieldy and has never taken hold in the local area.

The name White Mountains is derived from the conspicuous light-colored granite exposed on Montgomery Peak and Boundary Peak at the north end of the Range. There was long considerable confusion as to which summit was White Mountain Peak. In early years Montgomery Peak was given this name,

particularly by miners in the silver camp of Benton, just to the west of the impressive scarp of Montgomery Peak. An obviously higher summit, the loftiest point in the Range 15 miles to the south, also became known as White Mountain Peak, though none of its bedrock is white (Fig. 24, p. 53). Some early maps employed the cumbersome nomenclature "White Mountain Peak of the North" and "White Mountain Peak of the South." The issue was resolved with the publication in 1917 of the United States Geological Survey's 'White Mountain' quadrangle, on which the name White Mountain is given to the higher southern summit and Montgomery Peak to the lower one to the north.

The northern half of the Range, Northeast Owens Valley, and most of Fish Lake Valley are covered by this 30-minute 'White Mountain' quadrangle on a scale of 1:125,000. Currently (1962), all but the northeast quadrant of this quadrangle are being remapped on a 15-minute 1:62,500 scale. The southern half of the area is covered by a series of 15-minute quadrangles issued in the 1950's: 'Bishop,' 'Big Pine,' 'Blanco Mountain,' 'Waucoba Mountain,' and 'Soldier Pass.' Eastern Fish Lake Valley is covered by two older quadrangles: 'Silver Peak,' 1:125,000 (1900), and 'Lida,' 1:250,000 (1913).

On the 'White Mountain' quadrangle the elevation of White Mountain Peak is shown as 14,242'. Subsequent measurements by the United States Coast and Geodetic Survey and the United States Geological Survey raised this figure to 14,246'.

CHAPTER I

CLIMATE

Any air mass reaching the White Mountains area must have been much influenced by its trajectory over an assemblage of orographic barriers of varying width and altitude. By far the most important of these mountain barriers is the equally high Sierra Nevada, lying immediately to the west, which intercepts much of the moisture from winter-time Pacific storms. To north, east, and south are a series of lower ranges which have lesser climatic effects. Topographically, the least impeded avenue of approach for an air mass is from the southeast, but significant movement of air from this direction is infrequent. When it does occur, in mid-summer, the result may be spectacular thunderstorms with high precipitation intensities.

Weather Stations

Sparseness of population and inaccessibility of terrain have combined to produce a scarcity of reliable weather records. Fig. 3 (p. 10) shows the location, elevation, and years of record for weather stations in and immediately adjacent to the White Mountains. Table I (p. 11) gives the average monthly and annual temperatures for these stations, and Table II (p. 12) lists the corresponding precipitation data. Unfortunately, the years of record are for widely differing periods, and with the exception of Bishop (4,108') are of insufficient length for truly meaningful averages. The most complete data are from the Bishop station, maintained by volunteer observers from 1884 to 1947, with a break from 1919 to 1926, and operated since 1947 by the United States Weather Bureau as a first order station. White Mountain I (10,150') and White Mountain II (12,470') are maintained by the White Mountain Research Station, established in 1948 by the Office of Naval Research and the U.S. Naval

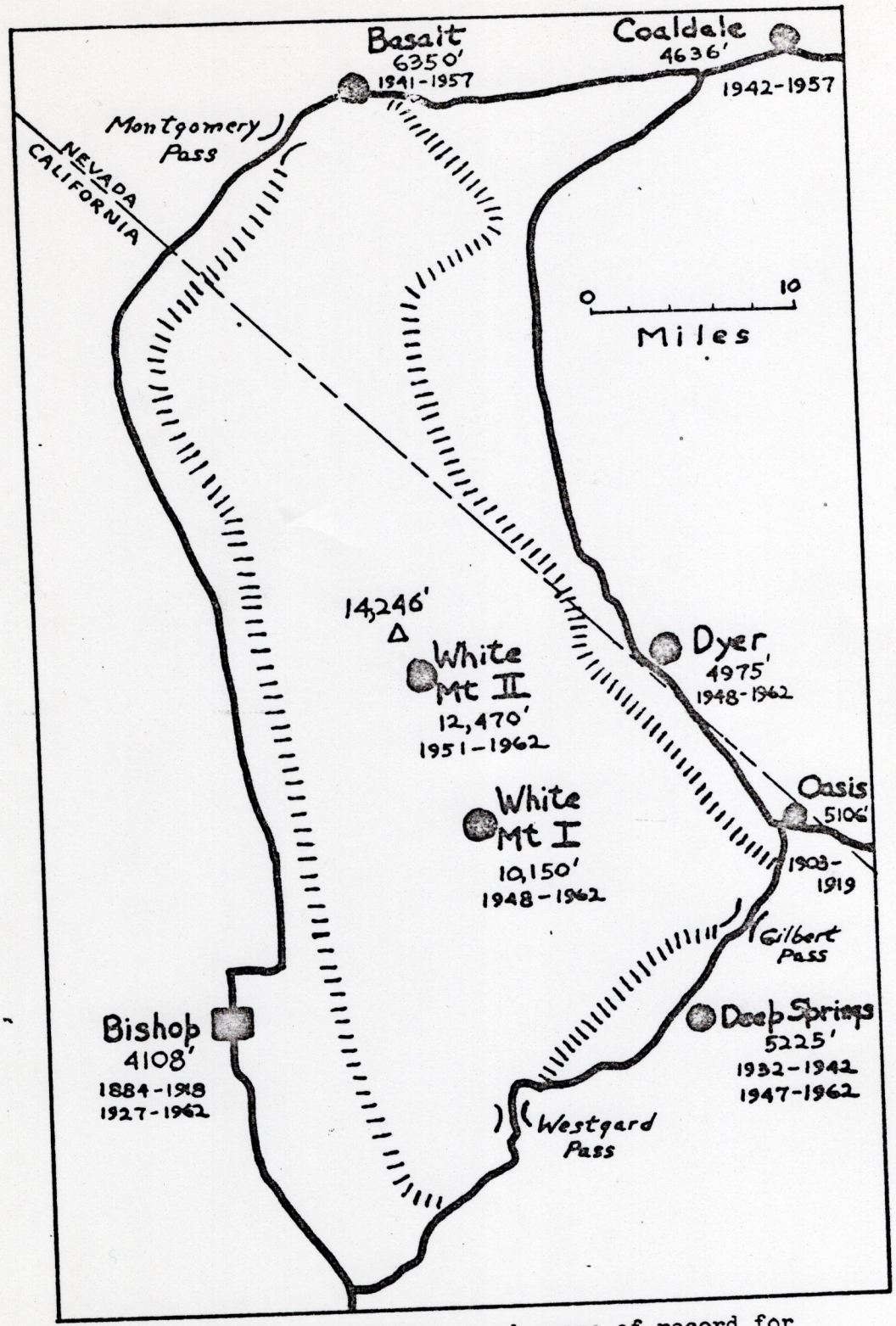

Fig. 3. Location, elevation, and years of record for weather stations in and near the White Mountains.

TABLE I

Average Monthly and Annual Temperatures for Stations in and near the White Mountains (°F)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Bishop	37.9	41.3	47.4	54.7	62.6	69.4	75.5	73.5	67.3	57.1	46.2	39.1	56.0
White Mountain I	20.4	21.0	22.2	30.3	35.7	47.0	52.7	51.4	46.0	37.7	27.8	23.7	34.7
White Mountain II	14.9	14.3	15.4	22.0	25.3	38.9	45.2	44.1	39.1	31.1	22.9	18.9	27.4
Deep Springs	27.4	32.8	41.4	50.6	57.8	67.6	72.6	70.9	66.4	53.6	41.0	29.6	51.0
Dyer	28.6	32.6	39.2	49.7	56.9	65.2	74.4	71.2	65.5	52.2	40.6	30.4	50.5
Oasis	29.4	34.3	41.3	49.6	55.3°	64.1	69.6	67.9	60.3	49.0	37.9	28.6	48.9
Basalt	29.1	33.3	38.2	47.8	54.2	61.2	70.5	68.5	61.8	50.4	38.6	31.3	48.6
Coaldale	32.5	39.2	43.5	54.3	62.1	70.4	79.2	77.0	69.6	56.0	42.3	34.9	55.1

TABLE II

Average Monthly and Annual Precipitation (in Inches) for Stations in and near the White Mountains

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Bishop	1.44	1.10	.72	.35	.22	.10	.11	.15	.21	.36	.56	.98	6.30
White Mountain I	1.32	1.90	1.04	1.18	1.56	.21	1.44	.63	.69	.56	.92	1.12	12.57
White Mountain II	1.53	1.79	1.44	1.39	2.43	.50	2.16	.93	.45	1.00	1.30	1.13	16.05
Deep Springs	.89	.74	.66	.60	.49	.12	.41	.20	.28	.30	.46	.79	5.94
Dyer	.60	.62	.41	.61	.58	.12	.48	.14	.26	.28	.36	.52	4.98
Oasis	.66	.57	.35	.41	.47	.26	.40	.41	.28	.27	.27	.42	4.77
Basalt	.41	.58	.34	.66	.54	.21	.49	.26	.25	.55	.51	.83	5.39
Coaldale	.22	.16	.23	.37	.34	.08	.52	.26	.09	.27	.31	.34	3.57

Ordnance Test Station at China Lake, California, and operated since 1950 by the University of California. Prior to 1952 the records at the two stations are incomplete; a 10-year period from July 1, 1952, to June 30, 1962, is used in the tabulations for both stations except where otherwise noted. Weather stations at comparable altitudes are rare any place in the world, and practically non-existent in the United States outside of Colorado. Basalt (6,350') has been run by the Nevada State Highway Department; the station was moved to Montgomery Pass in 1958. Although 800' higher and on the crest, precipitation at the new location seems very little greater than at the old. Deep Springs (5,225') is maintained by Deep Springs College, Dyer (4,975') in Fish Lake Valley by a volunteer observer. Oasis (5,106') and Coaldale (4,636') were operated by volunteer observers.

Temperature

The summer visitor to Owens Valley at mid-day may well think the valley and the apparently barren, flat-lighted slopes of the White Mountains to the east to be under the full possession of the sun with a forbidding aspect of heat. The same visitor to elevations above 10,000' in the Range would likely comment, perhaps complain, about the cold. In July average daily temperatures are 70° or higher at all valley areas with minor exceptions; maximum daily temperatures have reached 110° at Bishop, 106° at Dyer, 105° at Deep Springs. The decline in average July temperature values is close to 3.5° per 1,000' rise in elevation as measured at White Mountain I and White Mountain II. A maximum day-time temperature of 76° has been recorded at White Mountain I in June and July, 72° at White Mountain II in July. It would be a rarity at either mountain station for any summer month not to have one or more readings of 32° or below. In many protected areas at much lower elevations, where cold air settles, subfreezing temperatures can be expected during any

t of the summer. Frosts have been recorded even on the floor of Fish Lake Valley in July, at Bishop in June.

In winter there is less of a decrease in average monthly temperatures with rise in elevation then in summer. Between Bishop and White Mountain II the difference between average July temperatures is 30°, that between January temperatures is 23°. Corresponding figures between Deep Springs and White Mountain II are 27.4° and 12.5°. Cold air settling in the valleys seems to be the major reason; minimum readings in the valleys are significantly lower relative to minima in the mountains than are daily maxima. D'Ooge (1955, p. 177) suggests that this is an indication of a doming effect, with a maritime air mass of greater humidity overlying a more continental one and the White Mountains piercing a zone of maritime climate which slopes to the surface nearer the ocean.

Lowest winter temperatures at valley stations yet recorded are -15° at Bishop in January, -25° at Deep Springs in January, and -30° at Dyer in January; at the mountain stations the lowest have been -21° at White Mountain I in January and February and -32° at White Mountain II in March. Maximum-minimum thermometers which I have left at 13,000' just south of White Mountain Peak and at 11,000' a mile north of Boundary Peak have recorded lows of -38° at the former location, -36° at the latter, both occurring in 1952.

There is also a much greater variation of average monthly temperatures in winter from other seasons at all stations and elevations. Occasionally, a mass of abnormally cold air settles in the intermountain area for some weeks and causes much colder weather than normal. The last major invasion of such cold air was in the winter of 1948-49. In that year Deep Springs had a January average of 12.4° as compared to the long-term average of 27.4°. White Mountain I, 5,000' higher, was actually warmer for the same month, 12.5°. The years 1933 and 1937 also brought memorably cold winters to the region, with

a low of -42° recorded at the Lower McNett Ranch in northern Fish Lake Valley.

At both mountain stations February is as cold as January, and March is very little warmer. This retardation of temperature rise continues on through the spring with the first significant warming usually not occurring until latter May or first part of June. In the valleys it normally occurs in latter March or early April. White Mountain II has recorded -10° in May. Persistence of snow cover and greater frequency of spring storms at high elevations are chiefly responsible for this retardation of the spring temperature rise in comparison to the lowlands. In dry years with an early snowmelt, warming may be advanced as much as six weeks.

In the fall before the snowpack accumulates the rate of cooling is similar at all elevations. The first half of September is frequently a slightly cooler continuation of the summer months of July and August. The latter half normally initiates the steady decline in temperatures which continues into December. Though this decline appears linear in statistical averages, it usually is characterized by a sharp drop in temperature followed by several weeks of milder temperatures which in turn are terminated by still sharper drops.

The growing season at Bishop is approzimately 150 days, at Deep Springs and Dyer about 120 days. Average dates for killing frosts at Bishop are October 10 and May 10. Significant differences of growing season exist in the same valleys because of contrasting exposure to air drainage patterns. Most ranches in Fish Lake Valley have deciduous fruit trees for domestic consumption, but only the McNett Ranch, situated 600' above the valley floor on Indian Creek's alluvial fan, has a substantial harvest in more than one out of three years. At elevations above 7,000-8,000' the concept of growing season is meaningless as frost may occur any month.

Temperatures are colder in all but mid-summer on the east side of the Range and in the adjacent lowlands than on the west. The valley floors are

,000' higher in the east, and they are more open to influx of cold air from the north, less susceptible to unimpeded movement of warm air from the south. The longer and gentler east slope of the mountains provides more pockets for settling of cold air as well.

The diurnal range of temperature in the lowlands is large at any time of year, frequently 40 to 50 degrees. Clear skies and a lack of dense or tall vegetative cover promote rapid radiational cooling. On March 13, 1952, Deep Springs had a maximum of 73°, a minimum of 13°. A notable difference in diurnal range between White Mountain I and White Mountain II is evident, particularly in winter. The average minima of the two stations are very similar, less than a degree in January and February, but the maxima average 10 to 12 degrees higher at White Mountain I. Throughout the White Mountains average maximum temperatures decline with increased elevation, minima do not necessarily decrease.

Relative humidities throughout the entire area are low at all seasons, a factor making the high summer temperatures of the lowlands sensibly more pleasant to humans. This beneficial effect is counterbalanced in part by lack of shade and the high intensity of the sunlight. Intensifying the dry winter cold of the upper elevations are frequent moderate to strong winds blowing across open slopes.

Precipitation

Seasonal amounts of precipitation vary from 4" to 6" on the valley floors to 20" or a little more at the highest elevations. Unlike the Sierra Nevada totals appear to increase right up to the crest of the Range. An average increase of an inch and a half per 1,000' rise in elevation is indicated. Table III, p. 17, gives yearly totals, calculated first for a season from July 1 to June 30, second for a season from September 1 to August 31, at White Mountain I and White Mountain II. The purpose of the latter calculation

TABLE III

Seasonal Totals of Precipitation (in inches)
at White Mountain I and White Mountain II

July 1-June 30	White Mountain I	White Mountain II
1952-1953	10.84	12.97
1953-1954	15.06	12.03
1954-1955	9.42	17.69
1955-1956	16.97	22.57
1956-1957	12.61	17.85
1957-1958	15.37	15.93
1958-1959	7.22	15.65
1959-1960	8.88	9.22
1960-1961	8.97	11.13
1961-1962	19.45	26.59
Average	12.48	16.05

September 1-August 31	White Mountain I	White Mountain II
1952-1953	11.22	11.07
1953-1954	11.45	14.06
1954-1955	10.62	18.58
1955-1956	17.95	19.91
1956-1957	16.83	17.69
1957-1958	16.40	20.01
1958-1959	8.93	12.49
1959-1960	7.51	10.02
1960-1961	11.50	16.75
1961-1962	17.46	20.55
Average	12.99	16.11

is to add the important precipitation of July and August to that of the preceding 10 months, thus giving a better figure of the water available for plant growth, which at higher elevations occurs principally in July and August and ceases in September.

At Bishop totals from July 1 to June 30 vary from 1.69" in 1898 to 13.52" in 1952. The years 1901, 1911, 1914, 1916, 1937, 1938, 1941, and 1962 have been other wet years in Bishop during this century. At Deep Springs seasonal amounts have varied from 2" to 12", at Dyer from 2" to 10". In both cases 1952 was the wettest year on record. Unfortunately White Mountain II does not have a complete record for 1952, which was wetter than any following year.

Types of Storms

There are three types of storms that bring most of the precipitation to the White Mountain area; winter snowstorms from the west, spring snowstorms from the northwest and north, and summer thunderstorms from the south or southeast. The first, the winter snowstorms, is most important in accumulating snow in the mountains and substantial rainfall amounts in the valleys. Though it may come at any time from October through May or even June, the greatest frequency is from December through March. In this type of storm deep low pressure systems move southeastward along the Pacific Coast from the Gulf of Alaska. Fronts associated with these depressions move east and southeast across central and southern California, often in succession, 24 to 36 hours apart. This is the type of storm which brings to the Sierra Nevada nearly all of its high snowfall, and in crossing that barrier most winter fronts lose much of their energy. Cloud, strong winds, and snow flurries may be the only result in the White Mountains. However, the stronger fronts can and do bring major storms to the area, with 24-hour snowfall as much as 3' to 4' and rainfall of

1" to 3" in the valleys. Fig. 4 shows an intense storm of this type on Feb. 9, 1962, when 17" of snow fell at White Mountain II, 13" at White Mountain I, 1.80" of rain at Bishop, and 2.10 " of rain at Deep Springs. Fig. 5 (p. 21) shows a storm front spilling over the crest of the Sierra Nevada about two hours before reaching the White Mountains. This was on March 14, 1952; the passage of the front brought 45" of snow to the 13,000' saddle immediately southeast of White Mountain Peak. (The same storm front dropped 84" of snow at Crestview Highway Maintenance Station, 45 miles northwest of Bishop on Highway #395 along the east base of the Sierra Nevada at an elevation of 7,500'. This exceeds all listed 24-hour snowfall totals in the United States.)

The second important type of storm occurs in the spring, chiefly May, and is responsible for May being the wettest month in the last decade at White Mountain II, second wettest at White Mountain I. Its influence is noticeable in Fish Lake Valley and Deep Springs Valley, is minor in Owens Valley. As spring advances, the North Pacific anticyclone expands northward, blocking storm stracks moving across California earlier in the year. The Great Basin may still receive unstable air from the northern part of the Pacific, which enters the continent over Oregon, Washington, or British Columbia, and moves rapidly southward along a lee trough at the east side of the Cascades and the Sierra Nevada. This air yields precipitation, sometimes heavy, when striking mountain barriers like the White Mountains. Fig. 6 (p. 22) illustrates a storm of this type on May 14, 1962, which brought 26" of snow at White Mountain II, 18" of snow at White Mountain I, .38 " of rain at Bishop, .60" of rain at Deep Springs, and .68" of rain at Dyer. No precipitation occurred along the California coast north of Santa Barbara. Winds associated with storms of this type are from the northwest, north, or northeast. The east slope of the Sierra Nevada may be affected, but little or no precipitation falls on the west slope.

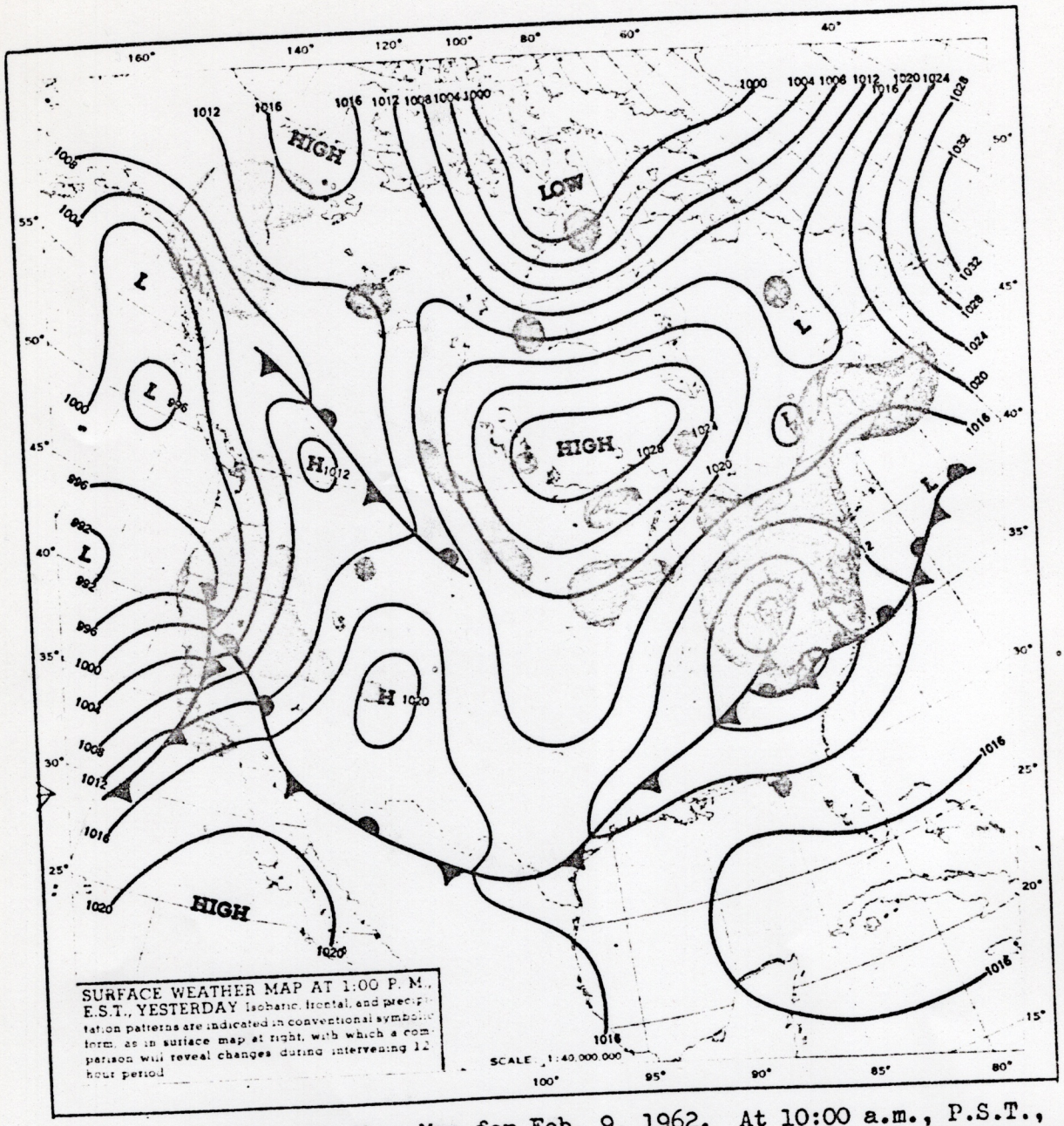
HIGH
LOW
HIGH
HIGH
SURFACE WEATHER MAP AT 1:00 P. M., E.S.T., YESTERDAY Isobaric, frontal, and precipitation patterns are indicated in conventional symbolic form, as in surface map at right, with which a comparison will reveal changes during intervening 12 hour period
SCALE 1:40,000,000

Fig. 4. Surface Weather Map for Feb. 9, 1962. At 10:00 a.m., P.S.T., an occluded front, associated with a deep low off the California-Oregon coast, is passing directly over the White Mountains, with a cold front closely following.

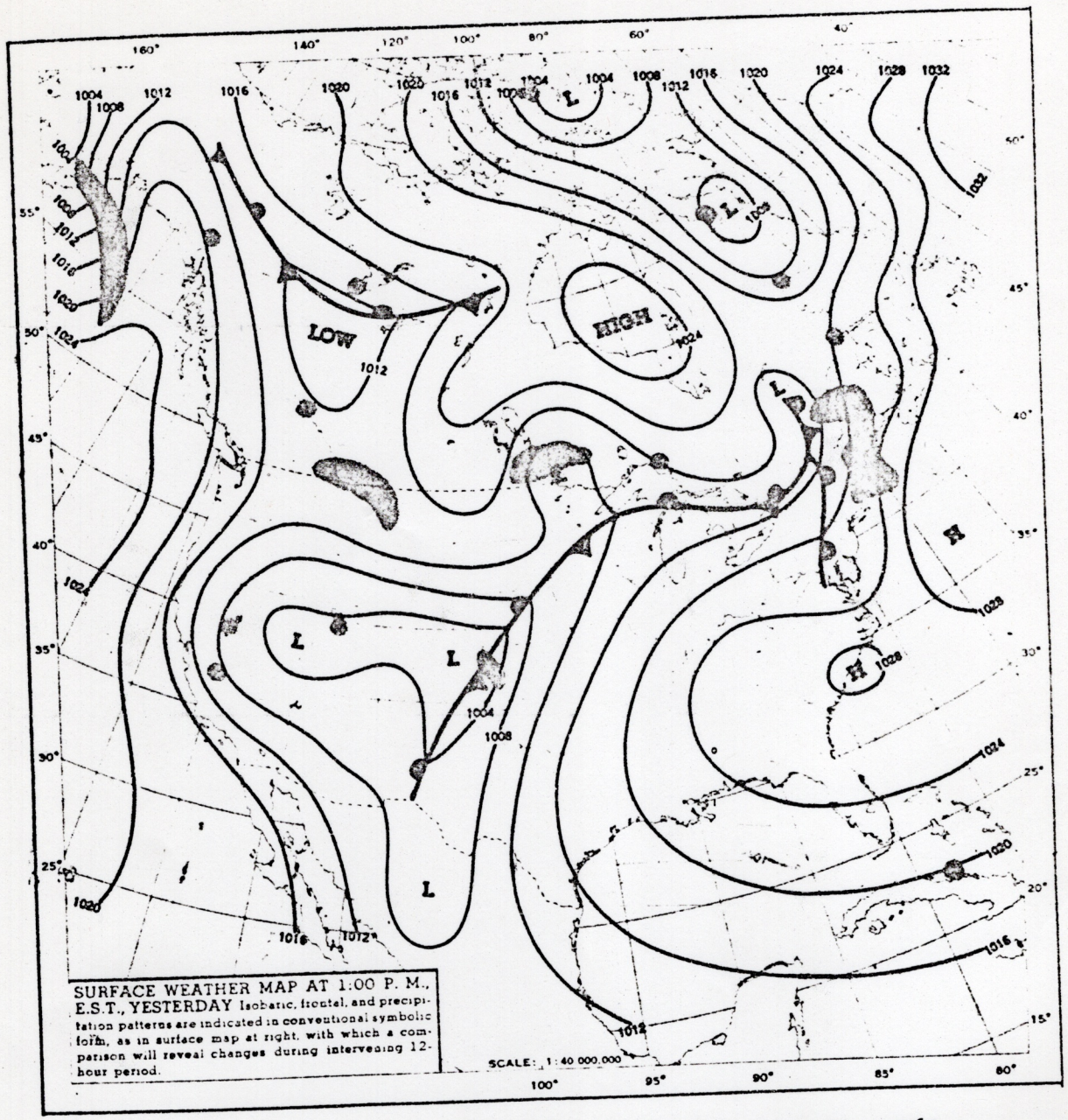
SURFACE WEATHER MAP AT 1:00 P. M., E.S.T., YESTERDAY Isobaric, frontal, and precipitation patterns are indicated in conventional symbolic form, as in surface map at right, with which a comparison will reveal changes during intervening 12-hour period.
SCALE: 1:40,000,000
LOW
HIGH
L
H

Fig. 6. Surface Weather Map at 10:00 a.m., P.S.T., May 14, 1962. High pressure exists off the California coast, but unstable air moves southward through low pressure on the east side of the Cascades and Sierra Nevada. A major spring storm affected the White Mountains on May 14.

The third major type of storm comes in summer, most frequently in the latter half of July. The flow of air from the south connected with troughs moving eastward across western Canada and northwestern United States sometimes becomes continuous with the flow clockwise about the western end of the North Atlantic anticyclone. Tropical maritime air from the Gulf of Mexico, or from the Gulf of California and the Pacific Ocean, is fed into New Mexico, Arizona, and southeastern California. Occasionally, this influx of unstable tropical air reaches the White Mountains and causes heavy showers. Such shower activity may continue in the general area for a week or 10 days in succession, with a very spotty distribution of precipitation. An inch may fall one place, .06" five miles away. The great bulk of the rain, often hail, falls in the upper elevations of the White Mountains; on rare occasions valley areas receive substantial amounts, but normally they are on the fringe of the intense shower activity. Owens Valley is much less likely to receive significant rain from this type of storm than Deep Springs Valley or Fish Lake Valley, though vigorous thunderstorm activity will affect the high elevations of the Sierra Nevada as well as the White Mountains. In some years the circulation pattern which causes this invasion of tropical maritime air from the south and southeast does not occur, and dry summers result. In other years, as 1947, 1952, 1955, 1956, and 1961, strong development of the pattern has brought concentrated rainfall with widespread flooding and major debris flows.

On July 23, 1955, the writer experienced an especially heavy rainstorm on Chiatovich Flat near Cabin Creek at an elevation of 10,500'. Southeast winds had brought thunderstorm activity into the White Mountains since July 19, and I carried a standard, 10" capacity, cylindrical rain gauge for several days on the good chance of measuring an unusual amount of rain in an area of no records. From 2:00 p.m. to 4:20 p.m. the catch was 8.46", most of which fell between 2:30 and 3:30. The first half hour brought an awesome and

ectacular display of cloud-to-cloud and cloud-to-ground lightning, accompanied by dense hail, the stones measuring up to a half-inch in diameter. A portion of this hail did not get into the gauge, so the total fall was greater than that measured. The hour of most intense precipitation was exclusively rain with very little lightning and thunder. Throughout the storm a moderate southeast wind, with sporadic strong gusts, funneled up the narrow canyon of Cabin Creek. The cloudbase, about 1,000' overhead, completely obscured the crest of the White Mountains, but occasional glimpses of sunlight on the Silver Peak Range to the east indicated the storm was forming along the east flank of the White Mountains. The rain ceased abruptly at 4:20 p.m.; by 6:00 the sky cover was two-tenths broken cumulus.

This storm of July 23, 1955 caused a massive debris flow north of Chiatovich Flat in the South Fork of Indian Creek. The debris did not flow past the canyon mouth, but a crest of water did reach the McNett Ranch at 5,600', 2 miles from the mountain front, and caused some flood damage. The ranch received a 20 minute shower (McNett, Ira; personal communication, 1955); Dyer had no rain; White Mountain II recorded 1.40". There has been much speculation about the amounts of rainfall involved in flash floods and debris flows in arid or semi-arid regions. Although small totals, falling in a short time on steep, barren rock or soil, may often be sufficient to cause flooding and extensive debris flows in many desert areas, this 1955 storm demonstrates that very large totals are involved in major debris flows in the White Mountains and may well be a necessary cause of them. Beaty (1960) reached the same conclusion. I have observed numerous high-intensity showers of durations up to a half hour which produced no major flooding or debris flows.

Fig. 7 (p. 25) shows the upper level circulation on July 23, 1955. Fig. 8 (p. 26) portrays a thunderstorm on the east side of White Mountain Peak on July 20, 1955. At no station in the area have 24-hour amounts even

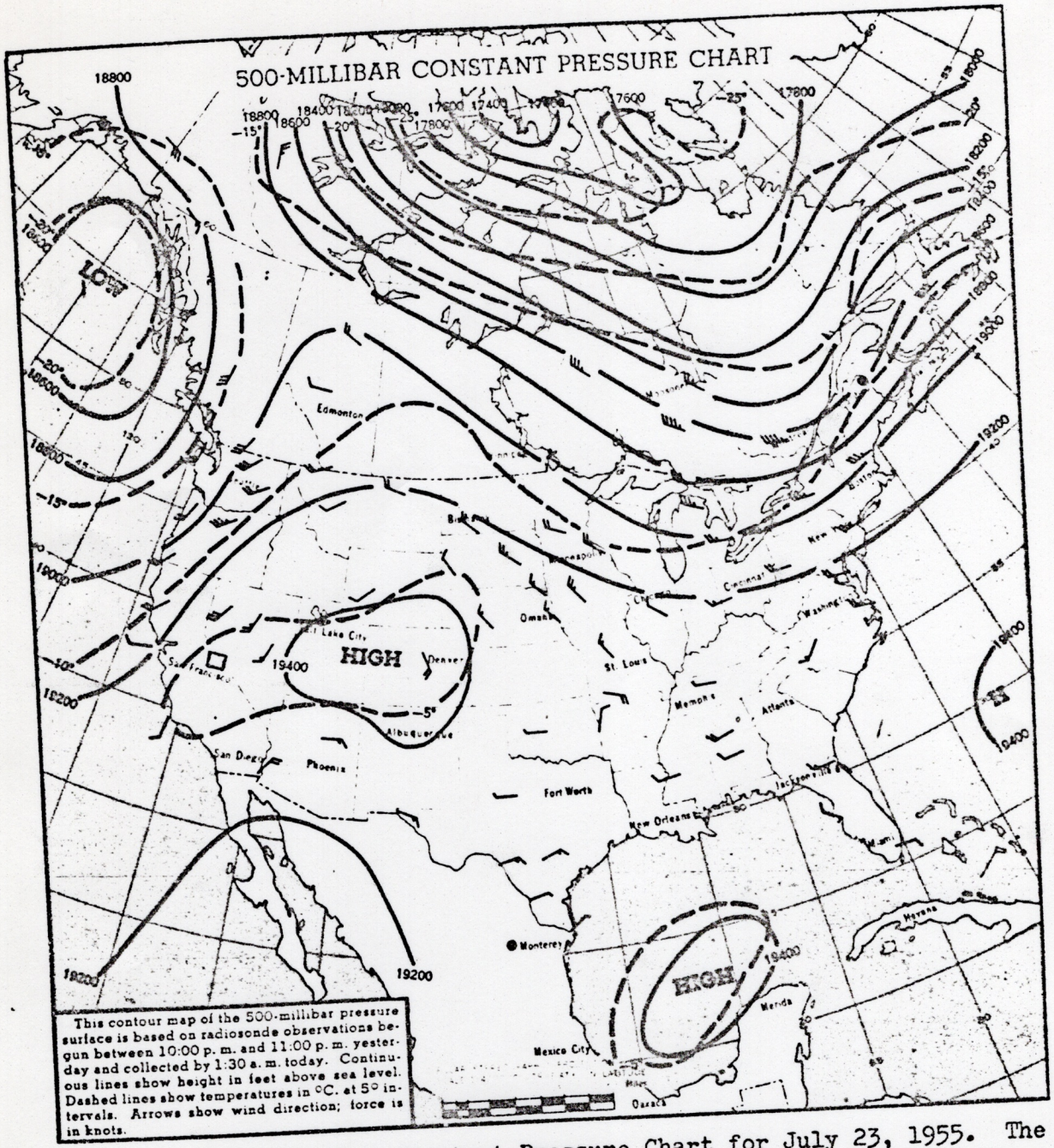

Fig. 7. 500-Millibar Constant Pressure Chart for July 23, 1955. The upper level circulation indicates the feeding of moist tropical air into the White Mountain region, outlined on the map. On July 23, 1955 occurred the heaviest summer rain yet measured in the area.

approaching 8" been recorded; Bishop has had 3.32", White Mountain II 2.70", both from winter type storms. It may well be that such heavy concentrations of rainfall are most unusual anywhere in the White Mountains but the rare occurrence has a most important role in influencing the morphology of the Range.

Minor amounts of precipitation may result from other types of storms. In summer unstable air from the west or southwest may cross the Sierra Nevada and result in thunderstorms over the White Mountains; these are usually of much less intensity than those approaching from the south or southeast (Fig. 9, p. 26). In fall, winter, and spring air moving south or southwestward from a strong high in the northern Great Basin toward southern California may cause snow flurries along the crest of the White Mountains (Fig. 10, p. 28). Strong winds from the west or northwest, not associated with a definite frontal passage, may also bring snow flurries. In either case true blizzard conditions may prevail--high wind, near or below zero temperatures, and an abundance of blowing snow (Fig. 11, p. 29). Such winds, as well as those accompanying the major storms, constantly reshape the surface configuration of the snowpack, especially on the summit upland, and blow considerable quantities of snow into the basins of the east slope.

Seasonal Distribution of Precipitation

From west to east in the White Mountain area there is an important difference in seasonal distribution of precipitation (Table IV, p. 30). Bishop has the typical regime of most California stations--winter wet and summer dry. White Mountain I and White Mountain II have precipitation much more evenly distributed throughout the year; with June, late summer, and early fall being the dry period. Deep Springs is more comparable to Bishop, but with a minor peak in July; Dyer is similar to the mountain stations.

TABLE IV

Percentage of Precipitation by Seasons
at Bishop, White Mountain II, and Dyer

	Winter Dec-Feb	Spring Mar-May	Summer Jun-Aug	Fall Sep-Nov	Winter half of year Nov-Apr
Bishop	56	20	6	18	82
White Mountain II	28	33	22	17	53
Dyer	35	32	15	18	63

onopah and Goldfield, Nevada, 50 miles farther to the east, have a seasonal distribution much like that of Dyer.

The preceding discussion of the types of storms indicates the reasons for this variation in distribution. Owens Valley is relatively more open to the passage of winter storm fronts, which lose energy while moving eastward; it is less subject to invasions of tropical maritime air from the south and is thus summer-dry. The upper regions of the White Mountains receive relatively more precipitation from the influx of unstable air from the north in spring or from the south in summer than any of the valleys because of their elevation. It is quite possible that the short-term record at the White Mountain stations presents anomalies which would be smoothed out in a long-term record. December and January seem especially low at both mountain stations and have been below long-term averages at most California stations from 1953-1962. However, the essential differences in distribution from west to east and with increase in elevation will prevail over a long-term period, barring important climatic changes which would affect the whole area.

Differences in Precipitation

Differences in yearly precipitation totals occur not only from west to east (Owens Valley is wetter than Fish Lake Valley) and with increase in elevation; very likely the values also increase from south to north. There are no station records to substantiate this assertation, but the experience of nearly all long-time residents of the area and of the writer is that the portion of the Range from Boundary Peak to White Mountain Peak receives more precipitation from both snowstorms and thunderstorms than the region south of the main peak. There are other indications. Random measurements I have made with a standard snow sampler at comparable elevations along the summit upland in 5 different winters show 20% to 30% more water in the snowpack north of

ite Mountain Peak, with the greatest amount at the headwaters of Chiatovich Creek. The northern part of the Range has greater streamflow, more extensive former glaciation, and a less xerophytic vegetation. (Lodgepole pine and Jeffrey pine occur only from White Mountain Peak north and there is generally a higher percentage of ground cover.) But it is difficult to separate the influence of possibly greater precipitation from that of other factors such as exposure, accumulation of wind-blown snow, and temperature at high altitude.

The higher average elevation of the northern part of the Range could be significant in causing greater precipitation there, as amounts seem to increase up to the crest throughout the White Mountains, but Pellisier Flats appears to be wetter than the summit upland of comparable elevation south of White Mountain Peak. In the Sierra Nevada, where precipitation and snow survey records are far more complete, there is a general decline in precipitation totals from north to south, despite increasing elevation. The frequency of frontal passage diminishes from north to south. The same relationship may have some effect on White Mountain winter-time precipitation. The Sierra Nevada is lower opposite the northern half of the White Mountains than the southern half, with two 9,000' passes on either side of Mammoth Mountain (11,053'), which is almost due west of White Mountain Peak. An extensive Jeffrey pine forest immediately east and northeast of Mammoth Mountain indicates the passage over the Sierra Nevada crest of considerable moisture which could possibly affect the north end of the White Mountains more than the south. Still another possible effect of the Sierra Nevada is that some fronts are retarded in crossing the massive barrier of that range. This, in turn, brings in cooler air from the north and northeast, which may underrun the front to some extent and possibly steepen its gradient. The same effect may be duplicated when a front passes over the White Mountain Range, which might account for the apparently heaviest snowfall in the Range in the upper

levations of the northeast canyons. Along the crest or east side of the Range and at White Mountain I and White Mountain II, the wind associated with a frontal passage from the west is often from the north or northeast.

Unstable air from the northwest in late spring strikes the high northern portion of the White Mountains first, and this could mean higher precipitation from this type of storm in the north. Tropical maritime air from the south reverses this relationship, but even so this air moves from lower to higher elevation as it proceeds northward. Statistical verification that more precipitation occurs in the northern part of the Range, particularly the north-eastern canyons, awaits establishment of instrument stations and snow survey courses in the area; neither is likely in the near future. Empirical evidence and the factors discussed above indicate strongly that this pattern exists.

Empirical observation also indicates that the buildup of cumulo-nimbus cloud in summer thunderstorms is much more likely to occur over specific portions of the summit upland than at random. Topographic influence upon air moving from characteristic directions is the probable cause. This would add a checkerboard pattern of precipitation distribution independent of more general patterns, such as an increase from south to north or with differences in elevation. Four areas of concentration of cloud formation have been noted by the writer. From south to north they are Sheep Mountain-Piute Mountain, the plateau just south of White Mountain Peak, the area just north of the Cabin Creek-Birch Creek saddle, and that portion of Pellisier Flats at the head of Chiatovich Creek. Common features of the four areas are rises in elevation from south to north and relatively broad lateral extent from west to east. White Mountain Peak seems relatively free from thunderstorms, perhaps because of a narrow summit area. Fig. 12 and Fig. 13 (p. 34) show thunderhead formation over these typical areas as seen from White Mountain Peak. Cumulo-nimbus may form over any part of the Range on any one summer day, and during intensive

storms most or all of the crest may be cloud-covered, but initial formation and greater subsequent development frequently occur over these four areas. There are very probably persistent patterns of winter precipitation at high elevation, but they are much harder to observe and are much complicated by later wind action.

Snowfall

On the summit upland above 10,000' over 80% of the mean annual precipitation falls as snow. Table V (p. 36) gives snowfall figures for White Mountain I and White Mountain II. The valley floors get 20% to 25% of their precipitation as snow, with wide fluctuations in the snow-to-rain ratio. The average annual snowfall at Bishop is 12", with a maximum of 59.8" in 1915-16. On Jan. 16, 1933 between 3' and 4' of snow fell on all the surrounding valleys of the White Mountains, a storm still regarded with awe by those who experienced it. In that day of primitive and scarce snow removal equipment, no vehicle moved in or out of Fish Lake Valley for four weeks after the storm.

Maximum recorded snow depth at the mountain stations is 94" at White Mountain I on March 16, 1952. At the same time the depth was greater, though unrecorded, at White Mountain II. On March 17, 1952, at 13,000' on the summit upland 3 miles north of White Mountain II, I measured 142" in an apparently undrifted area; though such are difficult, perhaps impossible to find. In most years depths any place in the Range are very much less, usually not exceeding 36" except in major drifts and with considerable bare ground on the summit upland and south-facing slopes. Fig. 14 shows a mid-winter snow mantle on White Mountain Peak during an above-average snow year (p. 37).

By the first of June in all but unusually heavy snowfall years the snow cover has disappeared from all elevations, but drifts persist throughout

TABLE V

Average Monthly and Seasonal Totals of Snowfall in Inches at White Mountain I and White Mountain II

	White Mountain I	White Mountain II
Jul	T	1.5
Aug	T	.6
Sep	2.3	3.9
Oct	6.2	9.9
Nov	10.5	14.4
Dec	13.4	13.6
Jan	14.1	18.7
Feb	21.1	20.1
Mar	12.2	16.8
Apr	14.5	16.5
May	16.4	27.3
Jun	2.6	5.6
Total	113.3	148.9

Seasonal Totals

	White Mountain I	White Mountain II
1952-1953	115.0	125.8
1953-1954	136.3	113.5
1954-1955	87.2	144.5
1955-1956	172.3	225.5
1956-1957	77.5	160.0
1957-1958	151.5	160.3
1958-1959	68.5	123.8
1959-1960	63.0	95.8
1960-1961	72.7	102.5
1961-1962	188.0	226.5

the summer on the summit upland and in protected northern and eastern exposures elsewhere. In many years there is a carryover of drifts at high elevation into the next season, but a dry period such as 1959-61 caused the vanishing of nearly al semi-permanent drifts. The break of slope at the east edge of the summit upland is particularly favorable for the formation of snow cornices, which are usually the last drifts to disappear (Fig. 15, p. 39). Because May is often a month of heavy snowfall, a distinctive feature of snow retention in the White Mountains is the quite frequent presence of larger snowdrifts on scutheast slopes than on northeast ones in early summer and the existence of more drifts on northwest slopes than on northeast in late summer (Fig. 16, p. 39). From year to year there is a conspicuous pattern of major snowdrifts appearing in the same locations (Compare Fig. 17 and Fig. 18, p. 40), the result of a complicated interrelationship of wind currents during and after snowfall and the influence of topography. A self-enlarging process takes place in that a small depression occupied by a small original drift is broadened, lengthened, deepened by nivation, solifluction, and run-off. The larger depression or gully catches more snow, which accentuates the denudational processes; the procedure may continue until enlargement of one depression or gully or coalescence of adjacent ones reduces the topographic contrast to the point where conditions are no longer favorable for snow retention. Structural controls--faults, joint systems, lithology--have much to do with determining the original position and subsequent development of snowdrift location.

On the valley floors duration of snow cover is seldom more than a month, usually only a few days, after deposition. Fig. 19 (p. 41) depicts snow cover in Northeast Owens Valley. Even the valley floors may get snow from October to May, but the great bulk of it falls in December, January, and February. Along the crest above 10,000' snow may fall any month of the year.

Wind and Lee Waves

"...you have not known what force resides in the mindless things until you have known a desert wind," wrote Mary Austin about this region (1950: p. 94). To a resident of the Island of Kerguelen in the South Indian Ocean or to a weather observer atop Mount Washington in New Hampshire neither the velocity nor the frequency of strong winds in the White Mountain area would be unduly impressive, though moving sand and alkaline dust in the lowlands and blowing snow in the uplands may be impressive enough to some one exposed to them in the White Mountains. In the valleys winds of 35 knots or more are most likely from October to November or February to April; they are usually from the north, occasionally from the south. At the crest of the Range strongest winds are most likely in winter or early spring, generally from the north or west, sometimes from the southwest in connection with the passage of storm fronts. Maximum one-hour wind velocity recorded at White Mountain II is 82 knots from the north in January, 1959. The most notable aspect of wind along the summit upland of the White Mountains is not high velocity, though that may occur, but constancy of moderate wind with conspicuous lack of calm, even in summer. At both mountain stations the prevailing wind is generally from the west throughout the year; although in winter north winds are frequent and in summer winds from the southwest, south, and southeast are common. The same pattern occurs in the northern summit area. During major winter and spring storms the upper air circulation over the White Mountsins, as shown on 500-millibar charts, is generally from the southwest.

When a constant wind blows over a mountain barrier, it often sets up large but invisible waves in the atmosphere, which may reveal their presence in characteristic cloud forms. Called 'lee waves' because they extend downwind from the barrier, they and their associated cloud forms are a distinctive meteorological element of this region. The lee wave of the Sierra Nevada,

termed the 'Sierra Wave,' is quite possibly the most powerful in the world; partly because of the 9,000' to 10,000' elevation above Owens Valley and partly because of the extremely clean shape of the Sierra Nevada's lee slope. As stratified air flows over the Sierra Nevada it first dips downward and then enters into a series of equally spaced waves. The wave length is determined by two factors; the stability of the air and the windspeed of the airstream (Scorer, 1961). Wave lengths usually vary from one to 10 miles; the longest are produced by strong winds and low stability. The amplitude of lee waves depends upon the shape and size of the mountain obstacle and the natural wave length of the airstream. As long as atmospheric conditions remain constant, the crests and troughs stay fixed in the same location.

Klieforth (Holmboe and Klieforth, 1954, p. 59) lists the following synoptic conditions associated with strong development of the Sierra Wave: an upper trough along the Pacific Coast with strong westerly flow across the Sierra; a cold front approaching California from the northwest; a high inversion near mountain top level; and a westerly wind profile with speed increasing to 25,000' or 30,000' with a large vertical shear through the high level inversion. These conditions are most likely to occur during the winter or early spring.

High lenticular alto-cumulus clouds, either singly or in bands, are the most characteristic cloud form indicating a wave development. They are found when the undulating currents of the Sierra Wave carry air above its condensation level. Other forms associated with the Sierra Wave, particularly if it is strong, are cap clouds over the crest of the Sierra Nevada and perhaps the White Mountains and a strato-cumulus rotor cloud which occurs in a horizontally rotating cylinder of air directly beneath the crest of a wave of high amplitude. These rotor currents are capable of raising dust from the floor of Owens Valley to heights above the mountain tops.

There is much variety in particular wind and cloud pattern in the Sierra Wave, and frequently lee waves, usually weaker, appear on the east side of the White Mountains. Fig. 20 (p. 45) is a generalized diagram of a Sierra Wave of high amplitude. Fig. 21 and Fig. 22 (p. 46) show associated cloud forms.

The synoptic conditions favoring development of the Sierra Wave are also those favoring passage of storm fronts over the Sierra Nevada and the White Mountains. Thus, the appearance of lenticular alto-cumulus cloud east of the Sierra Nevada crest, usually the first visible manifestation of wave formation, is an excellent, though not infallible, empirical aid to forecasting approaching storms; especially if this cloud has a well-developed north-south linear extent.

Owens Valley has long been used as a locale for the sport of soaring because of the Sierra Wave, and sailplanes have been much used there to study the phenomenon. By utilizing the uplift of a strong wave in March 1952, researchers Larry Edgar and Harold Klieforth set the world's altitude record for sailplanes, 44,255' (Scorer, 1961, p. 129). With pressurized cabins sailplanes could undoubtedly go higher with strong wave development.

Past Climate

Paleobotanical evidence from a site at the northern end of the Silver Peak Range, on the northeastern border of the White Mountain Range, on the northeastern border of the White Mountain region, indicates the existence of a Lower Pliocene climate that was warmer in winter and higher in annual precipitation than that of today (Axelrod, 1940). Axelrod concluded the oak-juniper savanna-woodland represented by the fossil Esmeralda flora meant a climate similar to that of present southern

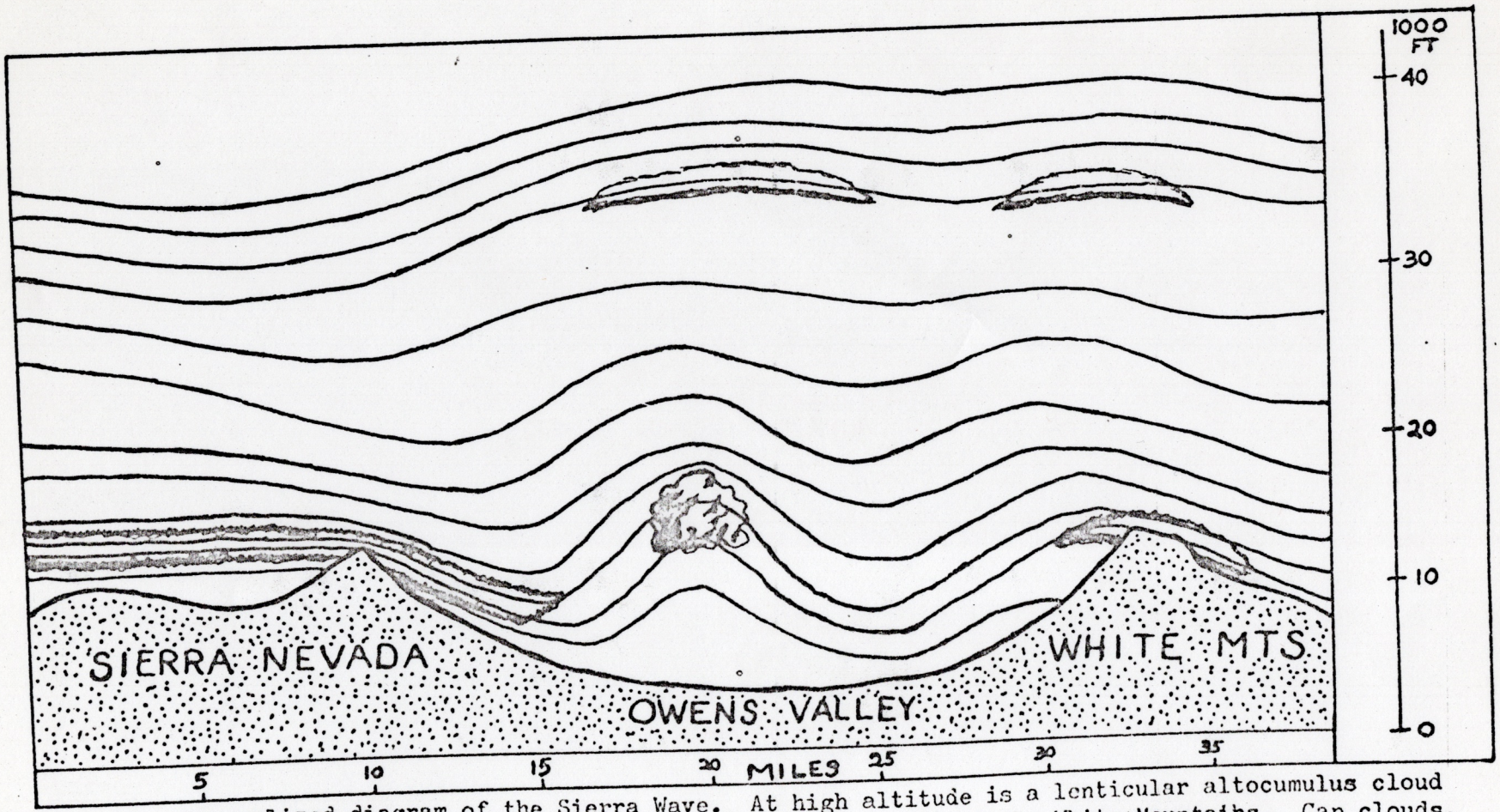

Fig. 20. Generalized diagram of the Sierra Wave. At high altitude is a lenticular altocumulus cloud over Owens Valley, with a smaller lenticular cloud over the crest of the White Mountains. Cap clouds, which descend partly down the east slopes, are shown over the Sierra Nevada and the White Mountains. A rotor cloud lies beneath the crest of a high amplitude wave. Adapted from Holmboe and Klieforth, 1954.

Arizona or the western slope of the southern Sierra Nevada. Rainfall then was 12" to 18" compared to 5" or less at the site now. The existence of this wetter climate would be most improbable if the Sierra Nevada, the White Mountains, and the fossil area were all at their present elevations. From paleobotanical, paleozoological, and geologic evidence derived from numerous localities, Axelrod states that rainfall amounts on both sides of the Sierra Nevada were essentially the same during the Miocene and Pliocene, that fossil floras indicate low summit elevations for the Sierra Nevada, and that the range came into existence as a major topographic barrier only after the close of the Pliocene (Axelrod, 1962). The White Mountains would have constituted a very effective topographic barrier with a much lower Sierra Nevada to the west; thus paleo-climatic evidence adds to geologic evidence that the major uplift of the White Mountains was during the Pleistocene.

Glacial deposits in the northeastern portion of the Range attest to a climate which was wetter, colder, or both, in the Pleistocene. These will be discussed further in Chapter III and IV.

The bristlecone pine (Pinus aristata) has been the object of much attention as an indicator of long year-by-year rainfall chronologies through its annual growth rings. The chief work on bristlecone pine dendrochronology in the White Mountains has been done by Edmund Schulman, now deceased, and co-workers from the Laboratory of Tree Ring Research at the University of Arizona (Schulman, 1956, 1958). Investigations from 1953-1957 in bristlecone pine areas of the Southwest disclosed that the trees of this species in the White Mountains were extremely sensitive in their growth ring patterns to variations in rainfall and that they much exceeded any other known species in years of longevity. Some 17 trees were dated as being 4000 years old or more, one as being 4,600 years

plus. Most of the old trees, which also tend to be the most sensitive for climatic chronologies, were found at or near the head of the South Fork of Birch Creek in the southern portion of the White Mountains at elevations from 9,000' to 10,000', growing on dolomitic rock only thinly weathered. In terms of soil and moisture this is a marginal environment for the bristlecone pine; a high correlation exists between old, sensitive trees and adverse sites, where growth is slow.

The possibility thus exists of extending climatic chronologies back hundreds, perhaps thousands of years, through tree-ring analysis of live and dead bristlecone pines. The methods of analysis and the results are not universally accepted; both the sensitivity to climatic fluctuation and the longevity of the bristlecone are questioned by some observers. An independent means of age determination, such as radioactive carbon dating, could do much to resolve the controversies. The writer spent some time with Schulman in the field in 1957, and can testify to the patience, care, and discrimination he and his co-workers used in the collection of field data. In 1961 and 1962 workers from Arizona and elsewhere have been in the bristlecone area on varied ecological and dendrochronological projects, so important additional knowledge of the tree's growth patterns and its usefulness as an indicator of past climate, should be available soon.

Schulman (1956, p. 52) found the tree ring chronology of bristlecone pine in the White Mountains for the period 1850-1950 to parallel roughly that of Jeffrey pine (Pinus Jeffreyi) in the Mono Basin, ponderosa pine (Pinus ponderosa) in the Spring Mountains of southern Nevada, and big-cone spruce (Pseudotsuga macrocarpa) in southern California. He considered these other species as especially sensitive rainfall indicators in those locales, suggested the correlation meant White Mountain

bristlecones also are particularly sensitive to rainfall.

Throughout its habitat in the White Mountains, 9,000' to 11,500' and mostly on lime or dolomitic rock, bristlecone reproduction is generally light and the old trees seem to be slowly dying. The cause may or may not be progressive desiccation; but if the present age determinations of the oldest trees are approximately correct, climatic conditions have not changed within the past 4,600 years sufficiently to exceed the tolerance limits of the trees living there now. This, in turn, suggests that no major change in climate has occurred in this time span.

CHAPTER II

GEOLOGICAL BACKGROUND

The first general study of the geology of the area was by Knopf and Kirk (1918), who mapped the southern portion of the White Mountains. From 1933 to 1937 G.H. Andersson did important work in the northern half of the Range. In the last decade the south end has been much studied by a number of workers, particularly C.A. Nelson, and has been the locale of several university summer field schools in geology. Fig. 23 (p. 51) is a geologic map of the White Mountain area, showing surface outcrops of the major lithologic units. From White Mountain Peak north to Trail Canyon the work is chiefly the author's; the rest of the map is largely derived from the following sources: Anderson, 1937; Blanc, 1958; Emerson, 1959; Gilbert, 1941; Knopf and Kirk, 1918; Miller, 1928; Nelson, C.A., 1962; Perry, 1954; and Pittman, 1958.

Lithology

Basically, the White Mountains consist of a core of granitic plutons of varied composition which have intruded sediments of Precambrian and Cambrian age. Overlying these are late Tertiary to Quaternary volcanic rocks. Granitic rocks occur chiefly in the north central and southeastern portions of the Range, sedimentary and metamorphic rocks in the south and west, and volcanics in the north, with scattered outcrops in the southeast. Percentages of the total area covered by each type are roughly 40, 45, and 15 respectively.

The sedimentaries are practically all affected by regional metamorphism, in some areas by contact metamorphism. The succession of Lower Cambrian and underlying rocks exposed in the southern White

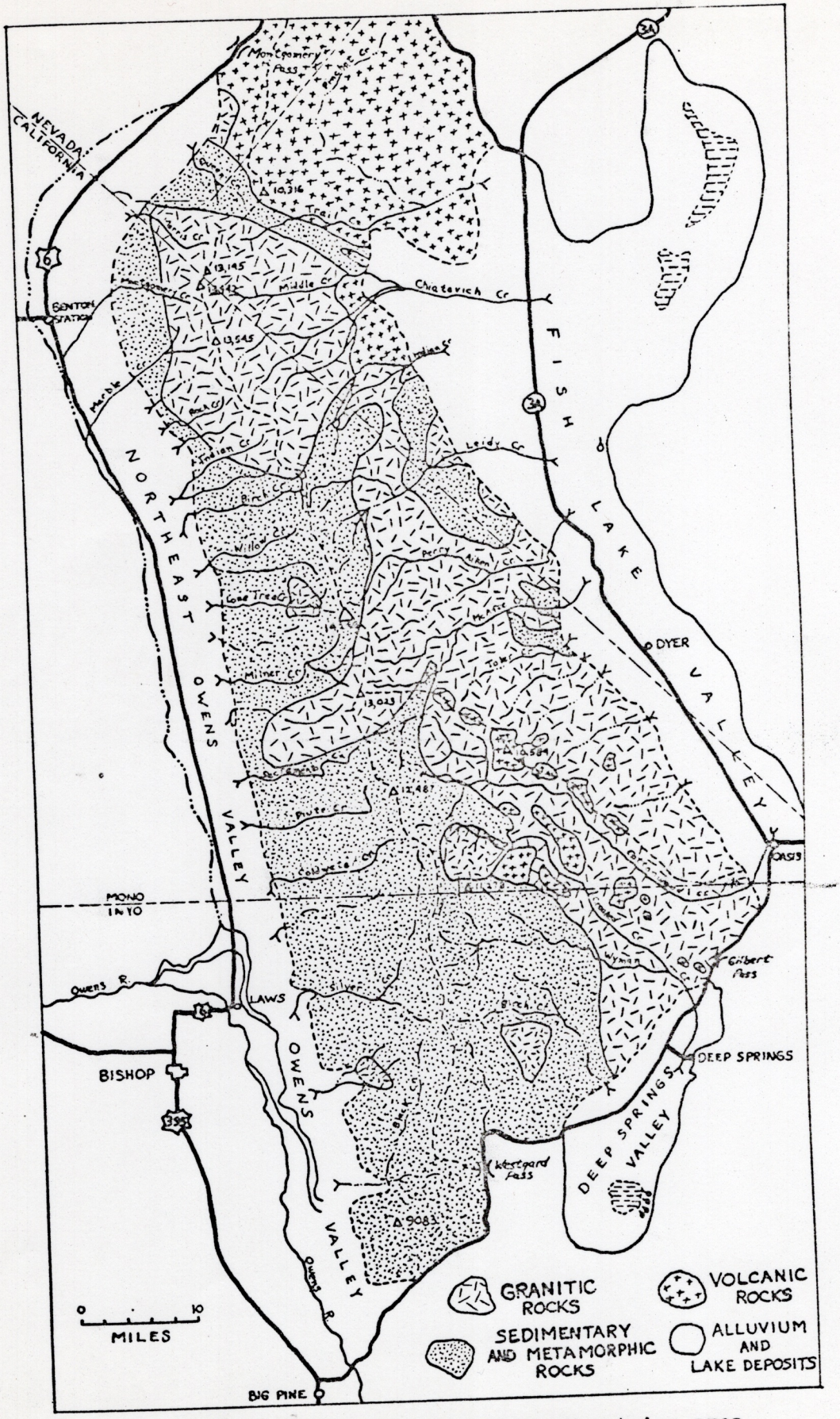

Fig. 23. Geologic map of the White Mountains area. For sources, see text, p. 50.

Mountains and northern Inyo Range represents one of the thickest accumulations of strata of this age in North America, approximately 21,000' (Nelson, 1962). The lowest five of eight formations have been named from type locality exposures at the south end of the White Mountains: Wyman, Reed, Deep Spring, Campito, and Poleta. Most prominent members of these formations are limestones, dolomites, and quartzitic sandstones, with interbedded argillites and shales. The most conspicuous member is the Reed dolomite, exposed along the crest and immediately east thereof for 16 miles north from Reed Flat, both because of its gleaming white to cream color and the growth upon it of bristlecone pines which do not appear on adjacent non-dolomitic outcrops. The sediments along the northeastern and northwestern flanks of the Range could very well correlate with the Wyman formation or Deep Spring formation. On the west slope from Milner Creek to Indian Creek and along the crest from White Mountain Peak to Birch Creek and Chiatovich Flat is a metamorphic complex of quartzites, volcanics, argillites, phyllites, and conglomerates. They are probably Precambrian, but ruggedness of topography, faulting, and intense metamorphism make stratigraphic relationships difficult to determine. Reddish, erosion-resistant quartzite with interbedded dark schistose volcanics is a conspicuous element of this complex; White Mountain Peak is composed predominantly of it (Fig. 24, p. 53). Freshwater lake deposits of Late Tertiary age in the region east of the White Mountains have been described by Turner (1900). There is a small exposure of this Esmeralda Formation in northeastern Fish Lake Valley which is not specifically shown on the map. Later Pleistocene lake deposits, saline playa deposits, and poorly consolidated alluvium comprise the most recent sediments.

The granitic rocks range from dark-colored diorites to very light granites and aplite dikes; field relationships indicate the successive

intrusion of increasingly more acid rocks.

Granites are more common than granodiorites, especially in the southeast; quartz diorites and diorites are least frequent. In the southeast porphyritic texture, with large phenocrysts of potash feldspar, is common; it is sporadic elsewhere. The orientation and spacing of joint systems vary greatly, a factor of much morphologic influence. Along some contact zones, especially between Indian and Leidy Creek and at the southern end of Pellisier Flats, contaminated areas of mixed granitics and metasediments occur. These areas are usually of narrow extent and have been designated as either granitic or sedimentary-metamorphic on the map.

In what has become a classic paper on granitization Anderson (1937) concluded that a large mass of igneous-appearing rock in the northern portion of the White Mountains (he named the mass Pellisier granite) was formed in situ by the recrystallization and replacement of pre-existing sedimentary and volcanic rocks. The cause of the conversion of this rock was the intrusion of the "Boundary Peak granite," a lighter-colored, more homogeneous, and more acid rock now exposed in much of the area. Emerson (1959) disagreed with this interpretation. He found no broad transitional zones of metamorphism; and states that the Pellisier granite consists of separate units, some of which are metamorphic though not granitic, while others are separate intrusive plutons of granodiorite with generally sharp contacts on their boundaries. Although no specialist in petrogenesis, the writer believes the field relationships support Emerson's conclusions.

The granitics have intruded Cambrian rocks, are overlain by Tertiary volcanics. Lithologically similar granite several miles southeast of the White Mountain area has been dated Middle Jurassic by the potassium-argon

method (McKee, 1961); probably most, if not all, of the White Mountain granitics are of similar age.

The volcanics consist of an older series of rhyolites, andesites, tuffs, and breccias (Late Tertiary to Pleistocene) at the north end of the Range which are similar to lavas widespread in Eastern California and Western Nevada; and younger basalts which overlie the older series in the north and occur in scattered flows in the southeast, mostly on the summit upland or broad interfluve areas. These blocky flows, vesicular toward the upper surfaces, reach thicknesses of 150'. They are much step-faulted at some locales, notably on Davis Mountain between the mouths of Chiatovich Creek and Indian Creek. From Montgomery Pass to the Owens River the west margin of the area is bordered by lava flows and rhyolitic tuff, the eastern edge of which is buried throughout much of its extent by alluvium from the White Mountains. There are some small volcanic exposures in Northeast Owens Valley.

Structure

The White Mountains are a fault block range of much complexity. The delineation of the marginal fault zones is clearest on the west and east sides. The date of faulting and the amount of displacement differ considerably from place to place along the Range, although fresh appearance of fault scarps, the preservation of extensive summit upland surfaces, the displacement of Late Tertiary or Pleistocene lavas, and fossil flora evidence (Aselrod, 1940, 1962) all indicate that most of the uplift has been during the Pleistocene. Recent renewal or continuation of diastrophism is shown by abundant fault scarps in the alluvium on both west and east flanks of the Range.

Faults are aligned in three principal directions. An older system is oriented southwest-northeast, is displayed in Silver Canyon and Black Canyon in the southwest and between Milner-Perry Aiken and Lone Tree-Leidy canyons near White Mountain Peak. A second series of faults runs east-west transversely across the Range. Pellisier Flats are traversed by a number of east-west faults and at the mouth of Toler Creek on the east slope sediments have been displaced left laterally as much as 1,500'. The third direction is north-south, or on the east flank northwest-southeast, which marks the marginal fault zones.

Everywhere the major marginal faults seem independent of stratigraphic structure, are steeply dipping, and are presumed to be normal. Within the Range thrust faults exist, particularly in the metasediments west and north of White Mountain Peak.

An anticline, with complimentary syncline on the west, trends northwest and pitches south. It is best developed in the south central portion of the Range, where Reed dolomite occupies a portion of its axis. In the northern part it broadens and is difficult to trace because of faulting, overturning, uplift and igneous intrusion.

Diastrophism is responsible for the gross morphology of the area, but detailed landscape features are much influenced by lithological and structural controls. Additional reference to these controls will be made in the topographic description in Chapter IV.

Mineral Resources

After the discovery of the Comstock Lode in western Nevada in 1859, prospectors, mostly from the gold fields of California, thoroughly explored the Great Basin ranges, including the White Mountains. During the next 50 years within a radius of 100 miles of the White Mountains

major gold, silver, lead, or zinc deposits were discovered at Aurora, Benton, Candelaria, Panamint, Bodie, Cerro Gordo, Darwin, Silver Peak, and Rhyolite; no major find of any of these metals has yet been made within the Range. The most important silver discovery was in Queen Canyon, Nevada, in the northwest near Montgomery Pass; activity there was greatest from 1870 to 1890. Value of production is difficult to determine, since ore was shipped to other districts, as Benton, Candelaria, and Virginia City. Estimates in the area reflect the generous influence of time and tradition; the writer believes total production did not exceed $2,000,000. It may have been much less.

Silver and gold prospects, with lead a minor accessory metal, have been worked down to the present day (Fig. 25, p. 58) but production has been negligible. Most silver claims, as well as the old mines in Queen Canyon, are in limestone or dolomite, usually at or very near intrusions of granite. Gold prospects are either placer or associated with quartz veins in sedimentary, metamorphic, or volcanic rock.

Mercury from cinnabar has been the most important metal of this century. The cinnabar occurs in a complex of Tertiary lavas, both flows, and tuffs, and phyllites and limestones in the Trail Canyon area of the northeast along the edge of Fish Lake Valley at elevations from 7,000' to 8,000'. Mining, active from 1927 to 1931, has been resumed on a large scale since 1958 by the Kollsman Mineral Company; the area is potentially one of the major centers of mercury production in the United States (Fig. 26, p. 58).

Scheelite, an ore mineral of tungsten, occurs in aplite and pegmatitic granites in the southeast, and much effort has been expended there in search for commercial quantities, with little success thus far. As with silver and gold, current market prices are not conducive to production.

Much mining activity has been concerned with industrial minerals. Salines (borax) were extracted for a brief period in the 1880's from the northern lake-bed in Fish Lake Valley, during World War I from the Deep Springs lake bed. Both operations were minor ones. Pumice deposits in Pleistocene tuff on the west border of the area and in scattered layers along the west slope of the White Mountains have been worked extensively, and are utilized only sporadically at present. Pyrophyllite, a mineral similar in appearance and use to talc, is obtained from a brecciated fault zone at the base of the west slope near Lone Tree Creek. The largest current industrial mineral operation in the White Mountains is the open quarrying of diatomite by the Great Lakes Carbon Corporation at the extreme northeast tip of the area near the mouth of Pinchot Creek. The mineral occurs in freshwater lake deposits, Pliocene or Pleistocene, overlain by basalt flows; production has been steady since 1946.

An unusual operation suspended in the same year was the mining of andalusite at several levels in quartzite from 7,000' to 10,000' in a dry canyon between Milner Creek and Lone Tree Creek on the west slope of White Mountain Peak. Begun in 1922 this mine was the only commercial source of andalusite in the world for much of its active period. The ore was handsorted at the mine, then hauled by mule back to the roadhead at the base of the mountains. Used in refractory ceramics, chiefly for spark plugs, andalusite became unprofitable to mine with the introduction of synthetic alumina.

Fig. 27 (p. 60) shows the location of the chief mineral deposits of the White Mountains.

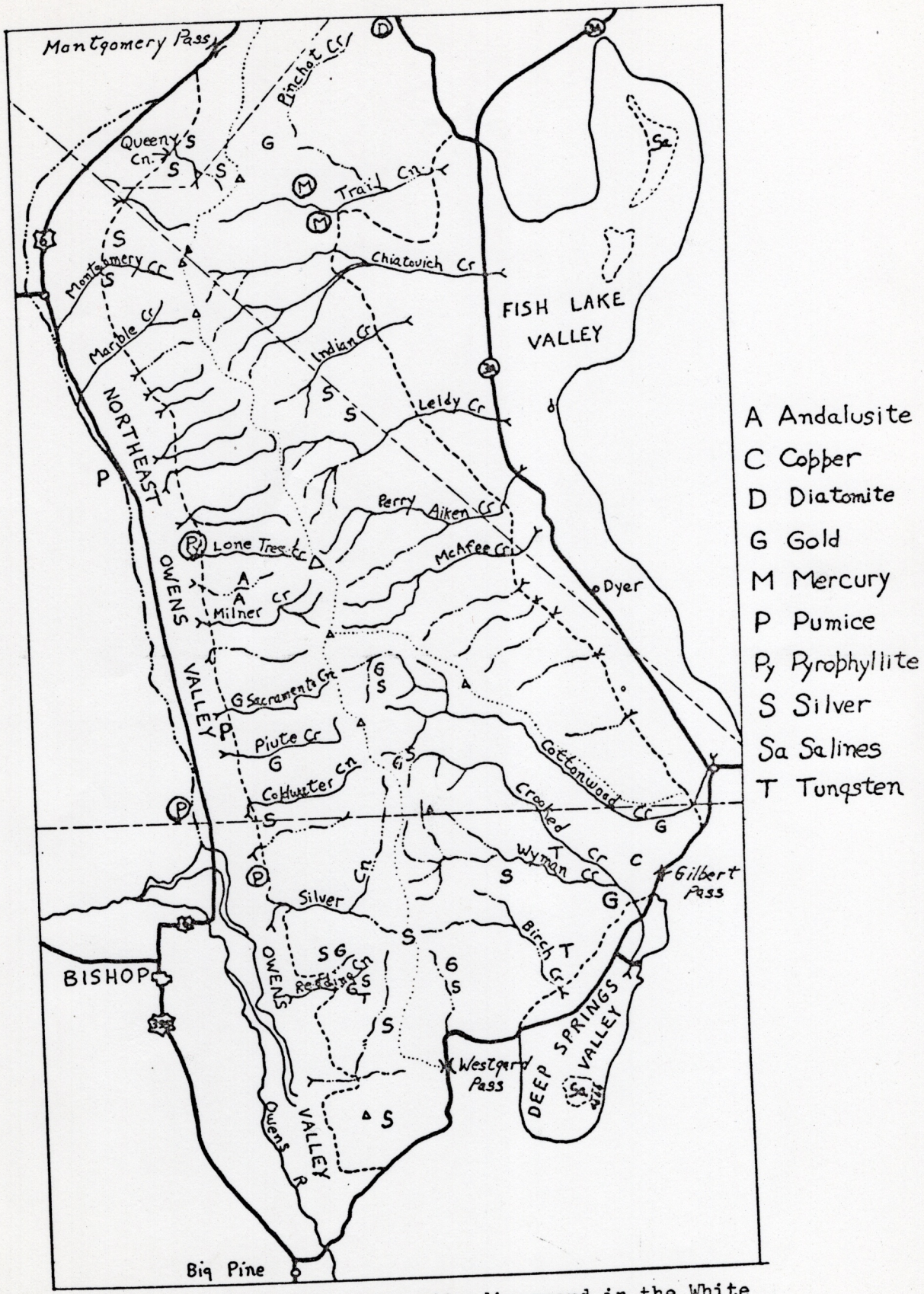

Fig. 27. Chief mineral deposits discoverd in the White Mountains. Encircled letters indicate mines with significant production since 1950.

CHAPTER III

TOPOGRAPHY

THE AREA IN GENERAL

The Mountains and Valleys

The White Mountains, the loftiest range in the Great Basin, have many characteristics typical of Basin ranges. Throughout its length there are no deep notches or truly isolated segments. There is a conspicuous straightness to the Range, both along the crest and the foot. In most portions there is an abrupt meeting of valley floor and mountainside, with recent marginal fault scarps in both alluvium and bedrock a common feature.

The most impressive aspect of the White Mountains is the massive scale of the topography. To an observer at either the base or the crest of the Range this massiveness is most apparent. The White Mountains loom much higher than any of the neighboring Basin ranges to north, east, or south. To the northeast, the Monitor Range, and to the southeast, the Spring Mountains, both 150 miles distant, can readily be seen from White Mountain Peak on a clear day across a succession of other ranges. To the west a 150-mile long segment of the precipitous east wall of the Sierra Nevada from Sonora Pass to Olancha Peak is visible. Visual impressions of scale are much accentuated by the deep troughs of Owens Valley and Fish Lake Valley, immediately adjacent to the west and east slopes of the Range (Fig. 28, p. 62).

The White Mountains are high both in altitude and in elevation above the surrounding valleys. At 14,246' White Mountain Peak is the third highest summit in California, being exceeded only by Mount Whitney (14,496')

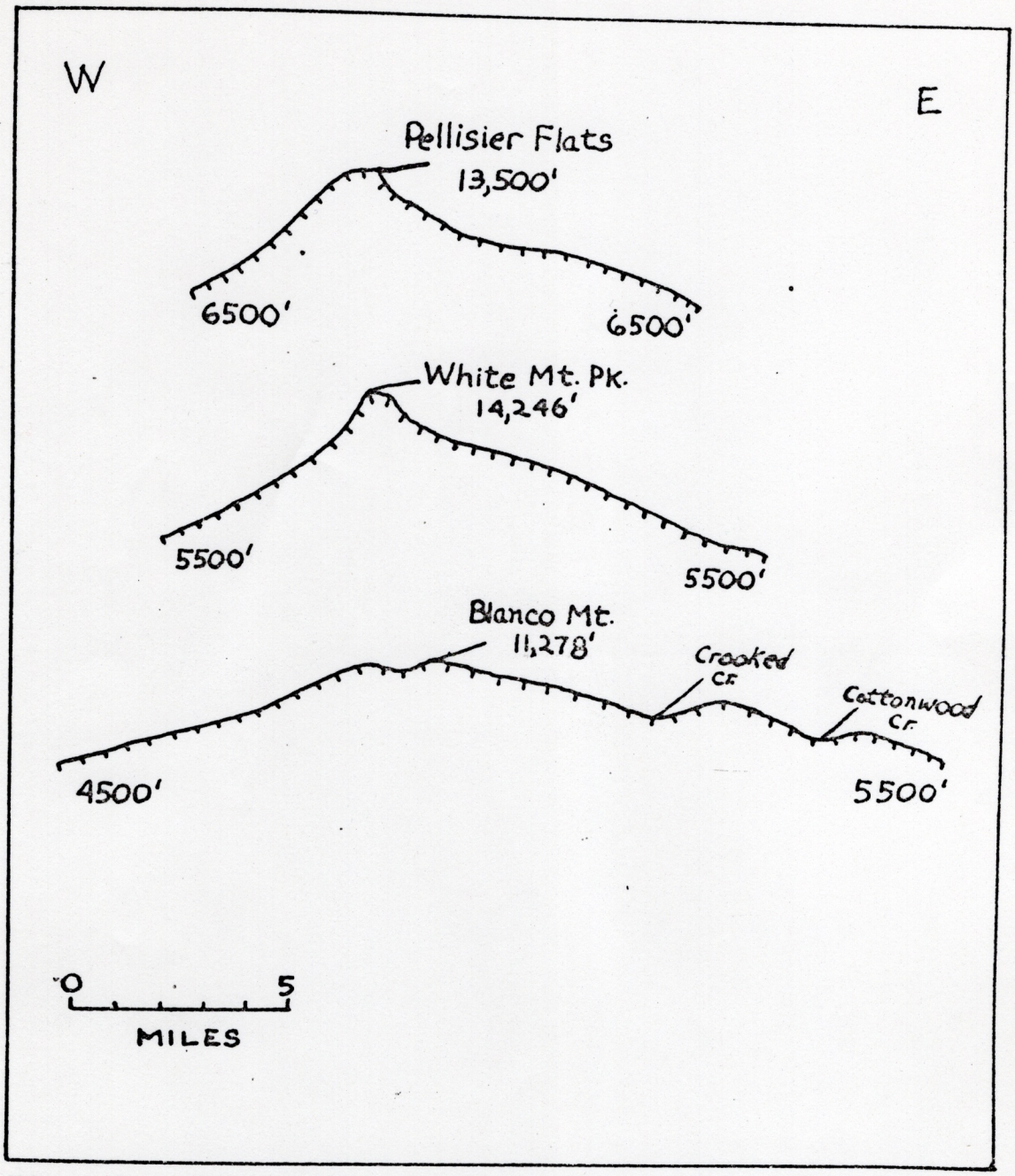

Fig. 38. Generalized profiles of west to east slopes of the White Mountains from Northeast Owens Valley to Fish Lake Valley. Vertical scale is twice the horizontal.

and Mount Williamson (14,375') in the Sierra Nevada; in the United States excluding Alaska 15 peaks are higher. About 12 miles of the crest in the northern part of the Range are above 13,000'; only at the north and south ends of the main crest are altitudes less than 10,000'. Differentials in elevation from crest to valley floor in terms of feet per mile are truly impressive. From White Mountain Peak to Northeast Owens Valley the drop is 9,700' in 7 miles (Fig. 29, p.64); from White Mountain Peak to Fish Lake Valley 9,250' in 9 miles (Fig. 30, p. 64). These figures are comparable to the greatest elevation differentials elsewhere in the Great Basin: Mount Whitney to Owens Valley, the Inyo Range to Saline Valley, and Telescope Peak to Death Valley. Except at the north, south, and south-east margins of the Range, the height of the crest above the valley floors exceeds 5,000'. (See Fig. 2, p.5 for location of place names.)

From north to south the crest rises moderately steeply from near Montgomery Pass at 7,000' to Mustang Mountain (10,316'), then steeply to Boundary Peak (13,145') and Montgomery Peak (13,442'). (Fig. 31, p. 65) A 1,200' notch separates these two peaks from Pellisier Flats, which extend for nine miles to an 11,200' saddle between Birch Creek and Cabin Creek. Four miles of the Flats are above 13,000' with a maximum of 13,545'. From the Birch-Cabin saddle the crest rises from 5.5 miles to White Mountain Peak (14,246'). From northern Pellisier Flats to the north slope of White Mountain Peak slopes are gentle, with a maximum relief of 500' along interconnecting ridges (Fig. 32, p. 66). The culmination of the crest, White Mountain Peak, does not appear from any direction as a sharp, distinctive summit, but rather as a graceful pyramid (Figs. 33 and 34, p. 67).

South of White Mountain Peak there is a moderate decrease of 1,000' in a mile, then 3 miles of summit upland to Mt. Barcroft (13,023'). Here

there is a bifurcation of the crest. The major branch continues south, gradually losing elevation for 15 miles to Reed Flat (10,000'). South of Reed Flat there is an abrupt drop of 1,500' in 1.5 miles, then a rolling descent for 6 miles to Westgard Pass (7,313'). Relative relief along this portion of the crest exceeds 1,000', as at Sheep Mountain (12,487') and Campito Mountain (11,543') at the head of Coldwater Canyon. There is a partly isolated summit, Black Mountain (9,083'), to the southwest of Westgard Pass. This high point of the west-east ridge dividing Black Canyon and Tollhouse Canyon is 1,700' higher than the low point of the crest at Westgard Pass.

The minor branch of the crest proceeds southeast from Mt. Barcroft, gradually losing elevation for 19 miles to 5,500' at the south end of Fish Lake Valley. This is generally a flat-topped crest with relief of 500-1,000' from the upper surfaces of extruded, interrupted basalt flows to the intervening granite. A lesser northwest-southeast crest separates Cottonwood Creek from Crooked Creek and is the drainage divide between Fish Lake Valley and Deep Springs Valley. Blanco Mountain (11,278'), 1.5 miles east of the main north-south crest between Crooked Creek and Wyman Creek, is higher than adjacent points on that crest (see Fig. 35, p. 69, and Figs. 36 and 37, p. 70, for general views of the White Mountains crest).

Throughout most of the Range the west slope is steeper than the east, with gradients as much as 2,000' per mile in the Rock Creek-Falls Creek area west of Pellisier Flats. An exception is the slope into Fish Lake Valley south of McAfee Creek where the gradient is as steep or steeper than in the southwest into Owens Valley. Fig. 38 (p. 71) shows west-east profiles through three sections of the Range. Aside from Black Mountain and Blanco Mountain there are no prominent peaks along the ridges leading

west or east from the major crests.

Longitudinal canyon profiles quite naturally reflect this difference in gradient between the west slope and the east. From Coldwater Canyon north to Montgomery pass average gradient of trunk canyons per mile ranges from 800' to 2,000' with most over 1,000'; on the east slope from McAfee Creek north gradients are 600' to 800' per mile. At the heads of the major east canyons extensive cirque development results in much steeper slopes for short distances; as much as 1,500' per mile at Indian Creek and Perry Aiken Creek. In the southwest part of the Range average canyon gradients are similar to those in the east without the oversteepened slopes at the head. Lowest per mile gradients are in the canyons of the creeks flowing between the two crests in the southeast; Cottonwood Creek and Crooked Creek have gradients of 300' to 400' per mile with some steepening at the canyon heads.

Pleistocene glaciation has occurred in all seven major canyons of the east slope from McAfee Creek north, also in Cottonwood Creek; the lowest certain moraines descend to 8,000'. On the west slope Milner Creek and Lone Tree Creek, just west of White Mountain Peak, have glacial deposits down to 10,000'. It is quite possible that other steep canyons to the north on the west side had minor glaciation, the traces of which have been eroded away or covered by later mass movement or debris flows.

All of the canyons have alluvial fans at their mouths; in Fish Lake Valley and the southwest, apices extend well back from the mountain front, as much as 3 miles in Middle Creek. In most cases the fans retain their identity for some distance from the mountain front, often more than half of the fan length, then merge on the outer perimeters with acute interfan depressions pointing downslope. There is no extensive belt of compound fans on any flank of the White Mountains, such as exists along much of

the east slope of the Sierra Nevada. The average slope of the fans varies in proportion to the steepness of the canyon; thus major fans on the west slope range from 3° to 8°, those on the east from 2° to 5°. Length of fan is seldom more than 3 miles on the west slope, is up to 7 at Chiatovich Creek in Fish Lake Valley. Most fans have a pronounced radial pattern, with radii of nearly equal length from canyon mouth to semi-circular perimeter. At present aggradation of the fans appears to take place chiefly from sporadic flooding or debris flows resulting from intense rainstorms, possibly from occasional rapid snowmelt. Nearly all fans are entrenched in their upper courses by their presently active channels, occasionally for as much as two-thirds of their length. Depth of entrenchment is up to 30' on the steep fans of the west slope, as much as 75' at the mouth of Chiatovich Creek on the east side. Most fans show evidence of recent faulting; on some major displacements have occurred. In the southwest between Black Canyon and Silver Canyon, extensive fan deposits exist as much as 2,500' higher than the present floor of Owens Valley. In Fish Lake Valley the fans of two major canyons, Perry Aiken Creek and McAfee Creek, have practically disappeared from relative down dropping of the valley along the mountain front.

The three valleys surrounding the White Mountains are all enclosed basins, though only a small portion of Owens Valley is adjacent to the White Mountains. All have generally steep sides, except for the volcanic area at the north end of Fish Lake Valley. With the exception of this same volcanic area the White Mountain margins of the valleys are also exceedingly straight. The few indentations and salients are nearly always the result of structural control for short distances of minor faults deviating at acute angles from the prevailing trend of the major marginal faults.

From geophysical evidence Bateman (1962, p. 107) states the depth of alluvial fill at the base of the White Mountains in the southwest is over 7,000', an astounding figure. He also indicates that many fault scarps parallel to the Sierra Nevada and the White Mountains are covered by alluvium in Owens Valley. In Fish Lake Valley a well near the mouth of Leidy Creek at a surface elevation of 4,870' struck granite at a depth of 1,010' (personal communication from W.S: Wright, well-driller). Two miles north another well at the same elevation was still in the alluvium at 1,002'.

Sand dunes exist in all three valleys. Always associated directly with water-deposited sand, they are found along old beach lines, river channels like the Owens River or the presently dry streambed at the east side of Fish Lake Valley, or at the mouths of creeks on flat valley floors. The latter sites appear usually to be indistinct deltas at the margins of former lakes. The dunes are seldom more than 10' high, generally less than 5'. They are partially to nearly completely anchored at present by vegetation, most commonly greasewood (Sarcobatus vermiculatus). Imperfect fixation by vegetation or local destruction of vegetation by over-supply of sand results in many small blowouts, particularly if the ridges are transverse to the prevailing strong north or south winds. In general the orientation of the ridges parallels the stream courses or beach lines, but local modification by wind often breaks up the dune ridges into a chaotic jumble of disconnected hillocks. Although local modification of relief is continucusly taking place, at present there appears to be no significant migration of dune belts (Fig. 39, p. 75).

All three valleys contain lakebeds, though that of Owens Valley is south of the area. These will be discussed further in the regional description in Chapter IV.

Drainage

By far the largest stream in the area is the Owens River, which derives no perennial surface drainage from the White Mountains. (Fig. 40, p. 75) Average annual flow of the Owens River is about 300,000 acre feet (records of Dept. of Water and Power, City of Los Angeles), most of which is in the river below the confluence with Bishop Creek 3 miles east of the town of Bishop. The largest stream draining the White Mountains is Chiatovich Creek, which is joined by Middle Creek and Davis Creek. There is nothing resembling a long-term flow record for any of the major White Mountain streams. The writer estimates the average rate of flow of Chiatovich Creek below the junction of all its tributaries at 6,000' in Fish Lake Valley at not over 15 cubic feet per second--cfs--probably closer to 12 cfs. This would mean an annual volume of about 10,000 acre feet, more probably closer to 8,000. Perry Aiken Creek and Cottonwood Creek are next in flow to Chiatovich Creek. Cottonwood Creek has the largest drainage basin in the Range, but much of it is at lower elevations in zones of lower precipitation. West side streams have much smaller flows, primarily because of smaller drainage basins. Largest stream on the west slope is Milner Creek.

White Mountain streams display a remarkable evenness of flow, most likely a result of the deep and extensive regolith covering all but the steepest portions of the watersheds. The effects of retarded flow from a snowy winter are noticeable well into fall of that season and even into the succeeding spring. Only the heaviest summer downpours and the most rapid snowmelts cause significant immediate rises in streamflow. There is a much greater time lag from snowmelt to streamflow in lower elevations in the White Mountains than in the barren granite canyons of the southern Sierra Nevada. This time lag is less pronounced in west side canyons

because of shallower regolith and more rapid snowmelt from greater exposure. During a snowmelt runoff in May, 1957, Beaty (1960, p. 126) roughly estimated a peak discharge on Milner Creek at 400 cfs to 500 cfs. This seems much too high to me--the capacity of the City of Los Angeles' Owens River Aqueduct, which takes most of the flow of the Owens River, is 400 cfs.

There is very little perennial surface drainage above 12,000', not much above 11,000'. Although these are the zones of heaviest precipitation and there is much terrain above 11,000', rock creep and solifluction flows tend to obliterate stream channels as fast as they form. On canyon floors of all but the major streams deposition of detritus, particularly from tributary canyons, will often cause surface flow to disappear for short stretches. At all elevations in the White Mountains the impression is strong that material is formed by weathering in much greater amounts than the streams, at present, can transport, with the exception of the sporadic intense storm. Most of the perennial streams in the White Mountains are found from White Mountain Peak to the lava area at the northeast end.

There are a number of springs, both in the mountains and valleys, generally associated with the following topographic, structural, or lithologic relationships. At high elevations springs emerge frequently at the base of solifluction flows, both on the summit upland and in the upper reaches of the canyons. On the summit upland another occurrence is in or near nivation depressions occupied by semi-permanent snow drifts. On the east side many springs are found associated with glacial moraines, and in all canyons at lower elevation they may occur on the downslope sides of particularly heavy colluvial fill. Some springs are related to lithology, as under basalt caps over granite, or along the Campito sandstone-Reed dolomite contact. In the valleys springs nearly always occur along faults.

Fish Lake Spring and related springs in Fish Lake Valley have an estimated discharge of 5.5 cfs or 4,000 acre feet a year (Eakin and Mason, 1950, p. 25).

There are no lakes at present within the White Mountains, although in the recent past there were small, shallow ponds or lakes associated with glacial moraines or with depressions on the summit upland in the southern part of the Range. Playa lakes form in wet years in northeast Fish Lake Valley and southwest Deep Springs Valley, seldom lasting through the summer.

Groundwater has been tapped for agricultural use and domestic supply in all three valleys, though not extensively in Deep Springs Valley or Fish Lake Valley. Eakin and Mason (1950) estimated that 20,000 acre feet of groundwater a year would be available for pumping in Fish Lake Valley. The largest groundwater reservoir in the area, that along the Owens River, is controlled by the City of Los Angeles, is pumped intensively during periods of low snow runoff from the Sierra Nevada. Groundwater levels are at or very near the surface in the lowest parts of all the valleys, including the small segments of Northeast Owens Valley dammed by White Mountain alluvial fans, with resultant deposition of salines from evaporation. In the agricultural areas on the valley floors water is generally encountered at depths of 20' to 50', with alternating water-bearing and dry alluvial strata to much greater depths.

During Pleistocene glacial stages surface drainage patterns were significantly different than those of today, not only in increased flow of streams, but in the existence of much larger lakes than the present playas and a major river through Northeast Owens Valley. Physiographic evidence indicates that Mono Lake at the east side of the Sierra Nevada overflowed its east rim at an elevation of 7,200' during early Wisconsin time, the Tahoe glaciation of Blackwelder (1931) and the Hilton glaciation of

Kesseli (1938). This probably also happened in earlier glaciations, but such evidence is lost and in later Wisconsin time Mono Lake did not rise enough to spill over the low point of its basin. The overflow in the Tahoe stage went southeast into Adobe Valley, where a narrow shallow lake was formed (see Fig. 41, p. 80). From there an outlet flowed into Northeast Owens Valley just west of Benton Station, and down that valley to a junction with the present Owens River. It is not clear just when Long Lake was drained by headward erosion of the present Owens River, but it probably occurred during Tahoe time (Putnam, 1960). Until this draining of Long Lake and perhaps even thereafter, the fork from Mono Lake would have been the larger stream. Small lakes existed in Northeast Owens Valley behind Marble Creek, Milner Creek, and Coldwater Canyon alluvial fans. Owens Lake of Tahoe time was connected to Death Valley by a continuous waterway, occupying successively Indian Wells Valley (China Lake), Salt Wells Valley, the Searles Basin (all 3 preceding valleys were covered for a time by Searles Lake), Panamint Valley (Panamint Lake), and Death Valley (Lake Manly). Death Valley, in turn, may have been connected during Tahoe time or earlier with the Colorado River system, either directly or indirectly through the Mojave River (Blackwelder, 1954b; Hubbs and Miller, 1948).

During late Pleistocene time, probably Tahoe, Fish Lake overflowed at the northeast end of the valley into Columbus Salt Marsh to form Lake Columbus, at least 200' deep. Possibly during the Wisconsin, but more likely earlier, Lake Columbus may have joined Lake Tonopah in southern Big Smoky Valley and Lake Clayton in Clayton Valley. At present only one set of old beach lines is clearly evident in Fish Lake Valley at an elevation of just over 4,800', accordant with the elevation of the outlet at Gap Spring. There may also have been a junction in pre-Wisconsin times

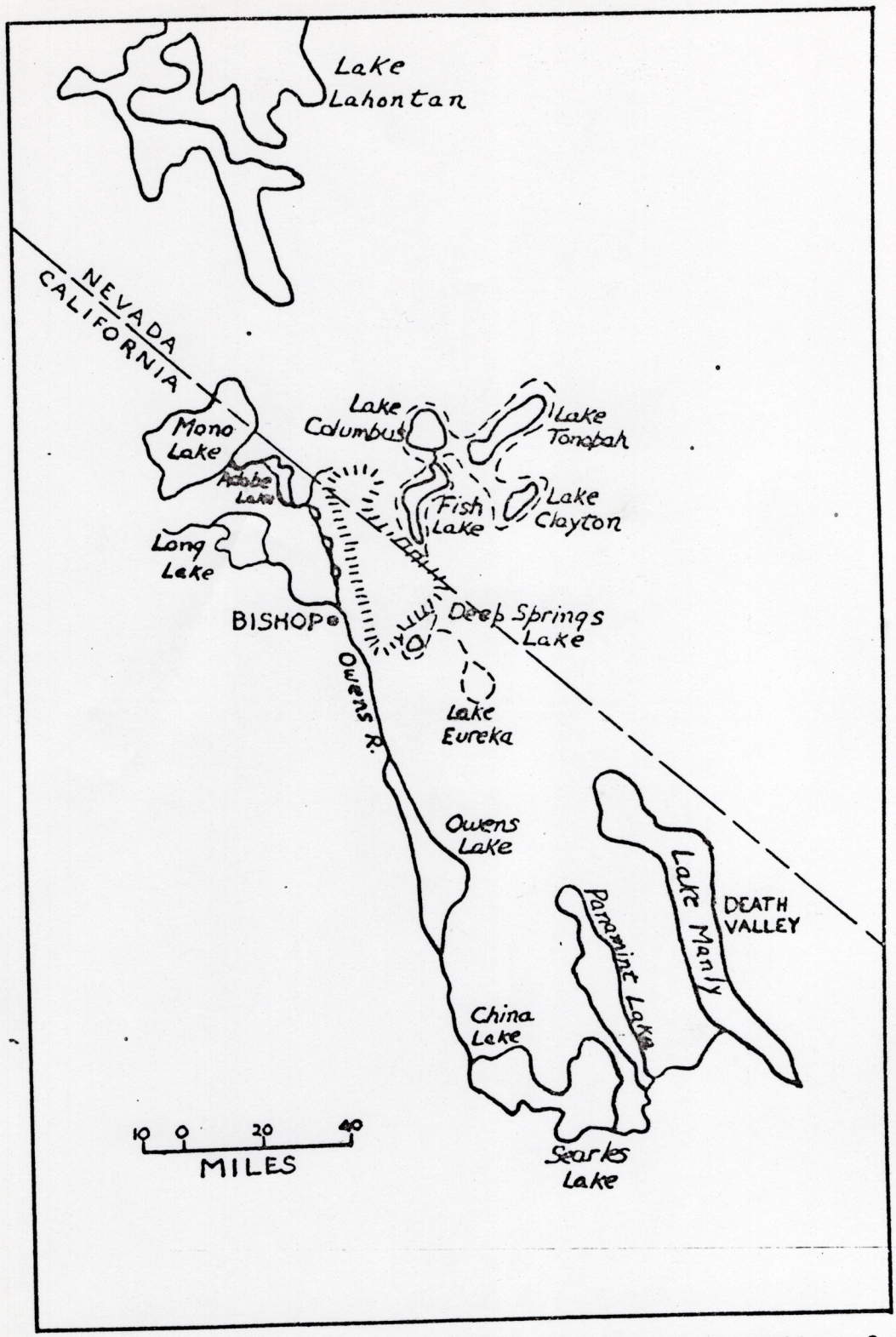

Fig. 41. Past drainage patterns in the vicinity of the White Mountains. Solid lines indicate reasonably certain pattern of early Wisconsin (Tahoe glaciation) time. Dashed lines indicate possible earlier systems on the east side of the White Mountains.

with Lake Lahontan, the known southern extension of which is shown on the map (Fig. 24, p. 53).

In Deep Springs Valley two sets of old beach lines are discernible, one at 4,960' and the other at 5,020'. The lowest present topographic gap is 5,550' at Soldier Pass in the northeast rim of the valley. Older appearing lakebeds, possibly Pliocene, occur in at least 4 localities in the calley at elevations from 5,200' to 5,500' (Miller, 1928, pp. 524-525). Darinage through Soldier Pass would lead to Eureka Valley, 2,500' lower, which does have Pleistocene lake deposits, although these have not been studied by the writer. The canyon from Soldier Pass into Eureka Valley also shows a fairly well-defined channel, quite possibly the result of drainage from an ancestral Deep Springs Lake, which would have been 12 miles long. In my opinion there has been a drainage connection between Deep Springs Valley and Eureka Valley, but in pre-Tahoe times.

Soils

Within the mountains there is nothing approaching maturity of soil development because of constant movement of the regolith. In the valleys no residual soils exist; in the alluvium only partial maturing has taken place, with some formation of hardpan layers in the older material.

Degree of slope, relationship to alkaline deposits, and proximity to streams are the important topographic influences upon soil for agricultural utility. Suitable for cultivation within the valleys is a narrow, irregular zone between the rough, coarse material brought down from the mountains and the valley floors with restricted drainage and an accumulation of alkali at or near the surface. This zone seldom exceeds two miles in width. Proximity to a perennial stream is important not only for the obvious advantage of water supply for irrigation, but because of

silt deposition by the streams alongside and near their present courses.

The writer assisted in a reconnaissance land classification in Fish Lake Valley in 1950 by the State of Nevada and the United States Geological Survey (Eakin and Mason, 1950). The results of that survey for the Nevada portion of Fish Lake Valley are shown on Fig. 42 (p.83). West of the Class II land, even below the edge of the White Mountain fans, the soil is too coarse textured for cultivation; on the east margin high water table and alkalinity make the soil unsuitable for development.

The largest area of soil suitable for cultivation is in the vicinity of Laws on the east side of Owens River. In the late 1870's construction was begun to divert water from the Owens River; 3 major canals resulted. Cultivation continued until the mid-1920's when the City of Los Angeles acquired the land with its water rights for municipal water supply. At present the canals carry water during periods of excess flow of the Owens River resulting in some discharge of groundwater in the area east of the river (Fig. 43, p. 84).

The story of the acquisition of property and water rights in Owens Valley by Los Angeles with subsequent cessation of irrigation and crop production is a celebrated, complex one, the emotional fervor of which has dimmed somewhat with passing years. Regardless of the political and ethical considerations involved, much misconception has existed to the effect that the whole of Owens Valley was or could be a pastoral paradise. In 1928 a soil survey of the Bishop area (Watson and Storie, 1928, p. 94) which included the Laws area concluded that 50% of the area was of no agricultural value, 12% of high value. With available water perhaps 5,000 acres would be used for crop production in the White Mountain portion of Owens Valley.

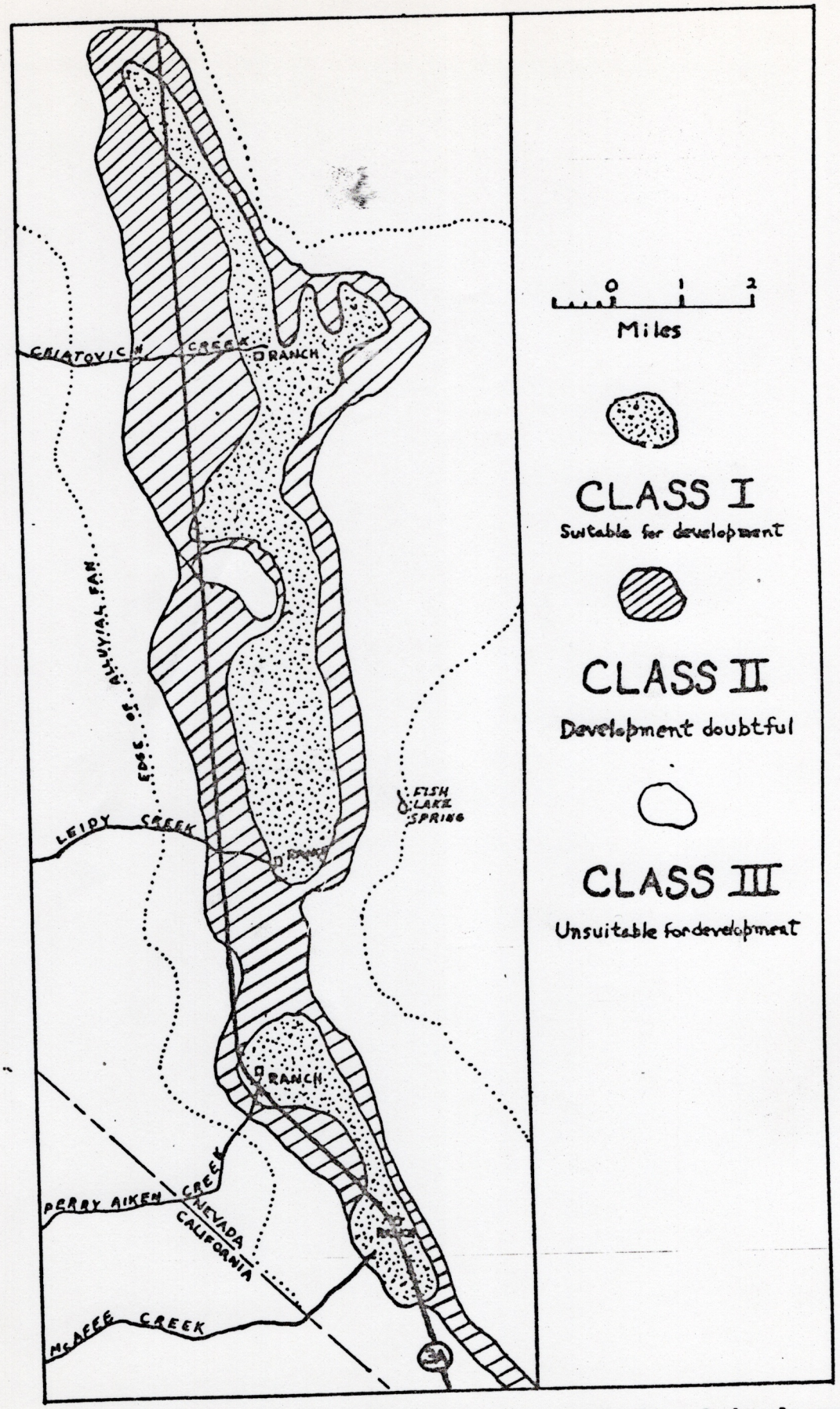

Fig. 42. Map of land classification for agricultural development in Northern Fish Lake Valley. Adapted from Eakin and Mason, 1950.

Agriculture in all of the valleys faces important physical difficulties in addition to limited areas of cultivable soil. A combination of high wind movement and light soils results in much erosion of newly planted fields or of grain and intertilled crops. Soil character usually makes the efficient distribution and application of irrigation water difficult and expensive. All available surface water outside of Owens Valley is presently being used for irrigation but amounts are inadequate during dry years; supplementary use of groundwater is increasing, but supplies are limited and pumping is costly. In this cold desert climate the growing season is short--150 days at Bishop, 125 days in Fish Lake Valley--with wide fluctuation from year to year. Especially damaging is the occasional killing frost in June.

Social and economic factors add to the physical difficulties. The area is far from population centers; other regions capable of producing similar crops are closer to Los Angeles and San Francisco. Large capitalization is necessary; at present most ranches are run on imported capital without the necessity of profit-making. In Fish Lake Valley, particularly in the last decade, a number of homesteads have been attempted by individuals with little capital, often with little experience. Unfortunately, most have failed (Fig. 44, p. 84), though the construction of a Rural Electrification Administration powerline through the valley in 1959 has reduced costs of pumping groundwater. Without significant population increase in the area, possibly a mining development or settlement in Owens Valley, or changes in present agricultural techniques, especially development of specialty crops adapted to the region, agricultural expansion in the White Mountain area will be slow and production will continue to be based upon alfalfa, irrigated pasture, and livestock. Quality of these products is high.

GEOMORPHIC PROCESSES

Summary

Although mechanical weathering is more important at higher elevations than lower because of greater frequency of frost and a larger supply of water, it seems clear that chemical weathering is more important than mechanical at all elevations. Hydration is probably the dominant weathering process in most of the area, especially in granites (Blackwelder, 1954a). The efficacy of weathering in contrast to the forces of denudation is shown by the few exposures of bare rock anywhere in the area; these exposures are mostly confined to the steep northwestern slope, to the walls of east side cirques, and to granitic outcrops with widely spaced joint patterns.

As a geomorphic agent wind is of importance in snow accumulation, in the formation and modification of low sand dunes, and in picking up fine material from the lower elevations and valley floors. The valleys may well suffer net loss of material, but quantitative data are totally lacking. During periods of strong south wind the west side of the area receives alkaline dust from the dry lakebed of Owens Lake, 60 miles to the south. Abrasive erosion by wind is quite minor throughout the area.

Glaciation, which has been important along the east slope, will be discussed later in this section.

Chief geomorphic agents in the White Mountain area are running water and mass movement, with slow flowage (rock creep, soil creep, solifluction) and rapid flowage (mudflow or debris flow) being far more important than sliding (chiefly rockfall). Terms of classification are from Sharpe (1938, p. 20).

In a thorough study of gradational processes in the White Mountains, Beaty (1960; also Kesseli and Beaty, 1959) concluded that wet mass movement

was the dominant denudational agent down to 10,000', that running water and debris flows were most important below that level (see Figs. 45 and 46, p. 88). Morphologically, the most significant cause of denudation within the mountain canyons and of aggradation on the alluvial fans (also the lower stretches of canyon floors on the east side) was found to be the summer cloudburst flood and resultant debris flow, such as those of July 26, 1952, and July 23, 1955. With minor qualification, such as the evidence of significant wet mass movement well below 10,000' on north and east slopes, the present writer agrees with these conclusions.

Human influence upon gradational processes has been minor. No logging of consequence has taken place and mining activities have occupied very little terrain. Overgrazing by cattle and sheep has affected some valley regions and local areas near perennial water in the mountains. The force of the 1952 flood, for instance, was felt principally in 3 canyons and fans on the west slope near White Mountain Peak that have never been grazed by domestic stock or otherwise affected by human utilization.

The impression is strong that the White Mountains represent a relict topography, that the agents responsible for the present forms are either largely inoperative now or much less effective than in the past, perhaps the recent past. Abundant evidence exists, such as former glacial deposits and past drainage patterns in the White Mountains and adjacent areas, that a wetter and/or colder climate prevailed in the region during late Pleistocene, and probably at intervals since. A wetter and colder climate would increase the efficacy of processes, such as frost riving, solifluction, and running water; thus, it is reasonable to assume that the general rate of topographic evolution is slower now than during much of

the last 100,000 years. However, it is my opinion from field observation that on occasional years heavy accumulations of snow or intense summer rains play a most important role in the formation of the topography.

The summer floods and debris flows of 1952 and 1955 were more severe than any previous ones in the memory of any resident of the area contacted by the writer; a time span going back to 1880. If this memory is correct, it still does not necessarily indicate that summer storms have all been of lesser intensity during this period, but might also suggest that a period of 75 years or more is requisite for the preparation of sufficient weathered material to become incorporated in the massive debris flows of 1952 and 1955. Heavy snow years occur much more frequently than intense summer cloudbursts and affect a far wider area. They deserve some attention, particularly in respect to nivation and solifluction on the summit upland.

Snowdrifts, Nivation, and Solifluction

The years 1952, 1956, 1958, and 1962 were seasons of well-above normal snowfall in most of the summit area of the White Mountains. In all of these years 15" to 30" of water, more in drifted areas, was stored in the snowpack for release in late spring and summer. Nivation depressions were frequently occupied by sizeable drifts well into the fall, some into the next year. There were numerous examples of mass movement of saturated debris during the summers of all 4 years, especially in the vicinity of the larger drifts. After heavy snowfall years, perhaps an average of one to three or four seasons, nivation is much accentuated and significant solifluction occurs only at such times. Very little wet mass movement occurred on the summit upland of Chiatovich Flat during or immediately after the intense summer rain of July 23, 1955, or with other heavy rains

experienced by the writer on the summit upland. The material in the large debris flows is evidently derived mostly, if not nearly entirely, from the canyon walls.

A key element in the effect of above-normal snowpack on geomorphic processes in the high elevations of the White Mountains is the percentage of the water content of the snow that is melted and stays liquid, and the percentage that is sublimated directly into the atmosphere or evaporated quickly from temporary water surfaces. No quantitative data on this problem in the White Mountains exist.

In late summer and early fall high elevation snowdrifts, with surface slopes of less than 30° to 35°, usually have pronounced suncups and sunpits (Figs. 47 and 48, p.91), terms suggested by Matthes (1934) for the cell-like hollows, a foot or two in diameter and from a few inches to several feet in depth. When typically developed, these hollows are closely spaced, the separating divides consisting of narrow blades and pinnacles of hard, granular snow, called nieve penitente. The hollows are aligned roughly in rows and sunk at a fairly uniform angle, all in the same direction. In the White Mountains angles vary from 45° to 60°, the direction is south to southwest. According to Matthes suncups and sunpits, deeper and sharper in form than suncups, are evaporation hollows, produced by the radiant heat of the sun from initial shallow concavities in snow-field surfaces. Typical sunpits develop only on mountains in low and moderate latitudes at high altitudes--above 12,000' in the Andes, 15,000' on Kilimanjaro in Africa, 16,000' in the Himalaya, and 12,000' in western United States. There seems to be no upper limit. They develop only on mountains that are exposed to strong insolation for prolonged periods, as during a dry summer. They form only in clean snow, the pinnacles and blades leaning at an angle corresponding to the elevation of sun at midday.

West and east walls of the sunpits receive more insolation than north and south; coalescence of adjacent pits and west-east trenches or furrows result. The pits maintain themselves until downwasting of the hollow reaches the ground surface; the blades may last much longer. Matthes maintained that suncups and sunpits are produced without visible liberation of meltwater and are at all times dry. He states that contribution to runoff from upper snowfields subject to snowpit formation is negligible.

My own observations in the White Mountains would verify Matthes' conclusions in regard to form and formation of suncups and sunpits, but would disagree substantially as to the amounts of meltwater liberated. I have commonly found meltwater along the walls and at the base of sunpits, especially in late season. The ground below and adjacent to large drifts with prominent sunpits is often saturated with water; actual runoff channels from high elevation snowdrifts are not infrequent (Fig. 49, p. 93). No doubt the relative percentages of melt or sublimation and evaporation vary considerably with variations in seasonal meteorological elements, such as warmth and velocity of wind, degree of cloudiness, and amount of summer rain. But the contribution of meltwater from high elevation snowdrifts with suncups and sunpits in the White Mountains is far from negligible.

Glaciation

Glacial erosion and deposition have been of much greater magnitude on the east side of the White Mountains than on the west. All east slope canyons that show certain glaciation were studied in detail: Trail Canyon, Middle Creek, both forks of Chiatovich Creek, Davis Creek, Leidy Creek, both branches of the North Fork of Perry Aiken Creek, South Fork of Perry Aiken Creek, both forks of McAfee Creek, and 3 forks of Cottonwood Creek.

No part of the summit upland, including the high east drainage of Cabin Creek, contained glaciers, at least in Wisconsin time. East slope glaciers began in east and northeast facing basins above 10,000' where conditions for snow accumulation and preservation were favorable. The greatest glacier length was 4 miles in Chiatovich Creek and Perry Aiken Creek.

Features resulting from glacial erosion are cirques at the canyon heads, small steps in the upper canyons, roches moutonnées, and limited areas of glacial polish (Fig. 50, p. 93). Overall widening and deepening of valleys from direct glacial erosion was slight. The pre-glacial stream courses of steep gradient had few tributary spurs which might have been truncated by glacial activity.

Morainal deposits are mapped in Fig. 51 (p. 95). Three substages of glacial advance are differentiated--termed Early, Middle, and Late from oldest to youngest (Fig. 52, p. 96). The lowest advance of each substage is shown on the map. Chief criteria used for differentiation were topographic position of moraines (whether higher or downstream; this was the most useful criterion), topographic expression of moraines (degree of gullying and preservation of end and lateral moraines), and the frequency and condition of surface boulders (useful in identification of Late moraines). The glaciers in the White Mountains were small, sluggish bodies with very high proportions of englacial and surficial debris to ice. Continuously deposited, hummocky ground moraine with few sharp-crested terminal or lateral loops is the general rule. Later moraines are superposed upon earlier ones but do not extend as far down canyon. There are seldom well-defined breaks between moraines; it is possible that the younger two substages represent relatively long periods of stability in the recession of one major glacial advance.

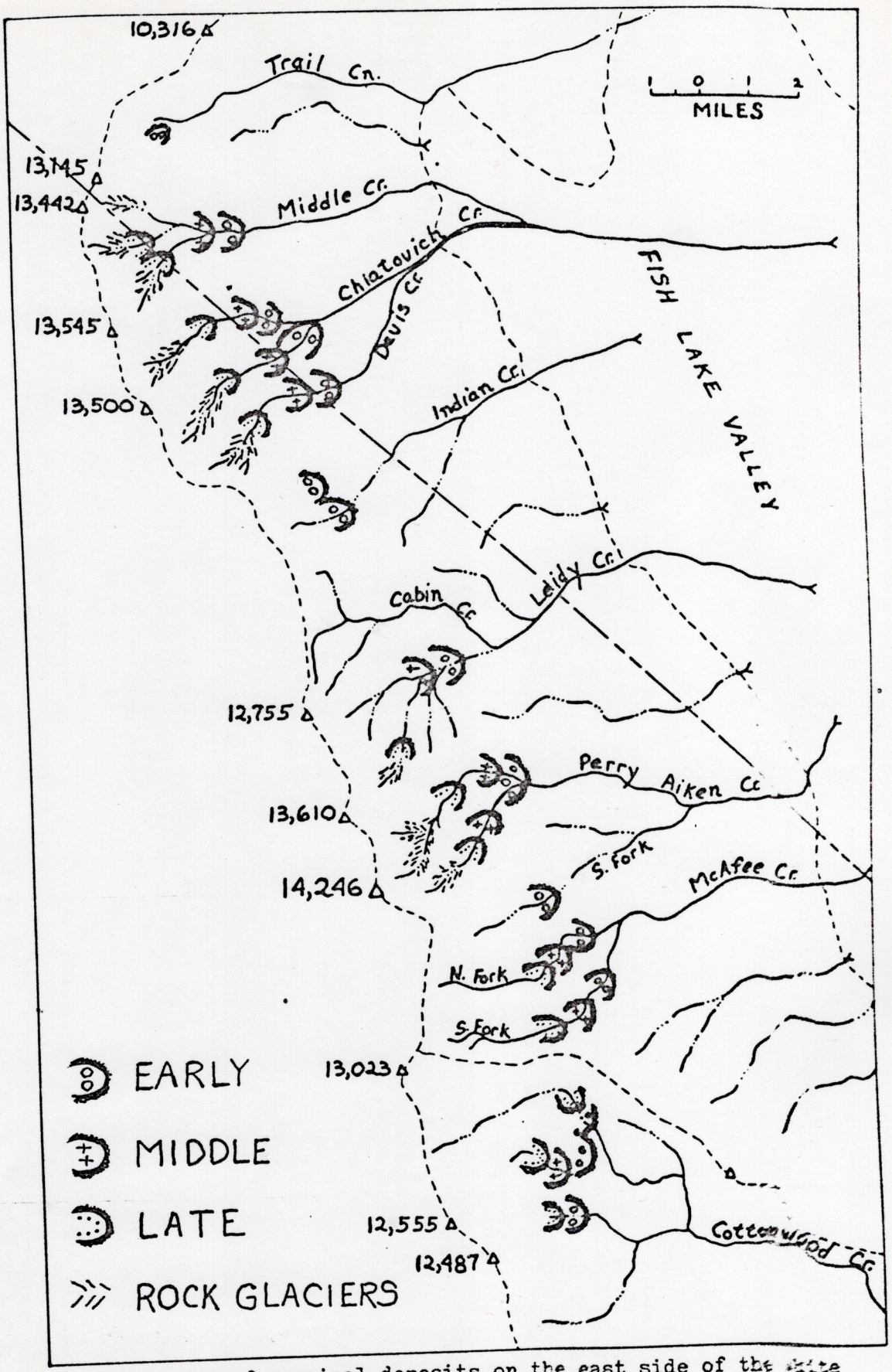

Fig. 51. Map of morainal deposits on the east side of the White Mountains. Early, Middle, and Late designate substages of Wisconsin glaciation; Rock Glaciers are undifferentiated.

At upper elevations in and just below the floors of the present cirques, blocky deposits of debris flows, solifluction flows, rockfall, rock creep, pro-talus ridges, and rock glaciers intermingle chaotically and make precise determination of chronology and separation of glacial from non-glacial material extremely difficult (Fig. 53, p. 98). Large aggregations of these deposits are undifferentiated as rock glaciers on the morainal map. One rock glacier at the east side of White Mountain Peak in the north branch of Perry Aiken Creek is a mile long. Within the White Mountains the writer leaves open the question of rock glacier origin, whether relict glacial features (Kesseli, 1941, interpretation from the Sierra Nevada) or masses of debris and present or former interstitial ice, owing their shapes to motion caused by the flow of the ice (Wahrhaftig and Cox, 1959, interpretation from the Alaska Range). Whatever the origin, rock glaciers in the White Mountains are recent features, probably associated primarily with the formation of small cliff glaciers or permanent snowfields during cooler and wetter periods of post-Wisconsin glaciation.

In all canyons Early moraines are the most voluminous and descend to the lowest elevations. They are 600' to 700' high in some canyons and descend to 8,000' at the junction of the two branches of Perry Aiken Creek. Most Early moraines terminate between 8,000' and 9,000', except in Cottonwood Creek where a flaring, gently sloping basin floor caused the glacier of this substage to spread out quickly and end at 10,200', and in Trail Canyon, which had only minor glaciation with lowest identifiable deposits at 9,700'. Moraines of the Middle substage resemble Early moraines in topographic shape and in degree of weathering and erosion. They are smaller in volume, and generally stand about a mile upslope and 500' to 1,000' higher in elevation (see Figs. 54 and 55, p. 99). Still farther

up canyon, usually 1 to 2 miles, are deposits of the Late substage at terminal elevations of 9,700' to 10,500'. These deposits are hummocky with few clearly defined terminal or lateral loops, but often have lateral moraine terraces. They are less dissected by erosion than the lower 2 substages and have a much higher proportion of relatively unweathered boulders and blocks.

The best sequences of moraines are found in the canyons of Chiatovich Creek, Perry Aiken Creek, and McAfee Creek. In some canyons (Trail, Indian, the north branch of Leidy Creek, and the South Fork of Perry Aiken Creek) a distinct Late substage is missing and the Early and Middle substages are not clearly separate. Trail Canyon heads in a small cirque below Boundary Peak with no extensive area of flat summit upland from which to accumulate windblown snow. Indian Creek and the north branch of Leidy Creek have large open cirques with relatively low floors, 10,000', in which glacial ice probably could not be maintained during the Late substage. There is no apparent reason for the light glaciation of the South Fork of Perry Aiken Creek; at present the flow of surface water in that canyon is very low for its size and elevation.

In topographic position and state of preservation the Early and Middle moraines resemble closely the Tahoe moraines of Blackwelder (1931) and the Hilton moraines of Kesseli (1938) along the east side of the Sierra Nevada and are tentatively correlated with this early Wisconsin substage of those two authors. The Lake substage in the White Mountains probably correlates with the late Wisconsin Tioga of Blackwelder and the Rock of Kesseli. This relationship is also similar to the Lamoille (Tahoe) and Angel Lake (Tioga) substages described by Sharp (1938) in the Ruby-East Humboldt Range of northeastern Nevada. Sharp (1960) also found moraines

of Tahoe and Tioga substages in the Trinity Alps of northwestern California. A possible difference in correlations is that the White Mountain Late substage is the last recessional period of the Tahoe, and that the larger rock glaciers at the heads of the canyons represent the Tioga. However, the writer prefers to consider the Late substage contemporaneous with the Tioga and that the rock glaciers formed either at the close of that substage or more recently, probably at both times.

The writer has found no certain evidence of glaciation older than Early, or Tahoe. The canyons of Perry Aiken Creek, McAfee Creek, and Cottonwood Creek offer the best chance of finding older stages, since the upper parts of these watersheds are in metamorphic rock, the lower in granite. Alteration of stream course from mountain uplift has occurred in all of these canyons; this greatly complicates interpretation of metamorphic deposits on granite in present anomalous positions, such as along ridges or above contemporaneous alluvial fill.

After a short reconnaissance trip in the lower drainage of Perry Aiken Creek, Blackwelder (1934, pp. 220-221) identified the remnant of a "probable Tahoe moraine" at 6,500' on the south side of Perry Aiken Creek two miles back of the range front and described ancient till of metamorphic rock mantling granitic ridges of the canyon even lower and closer to the canyon mouth. He postulated that an older glacier debouched onto Fish Lake Valley. Blackwelder never saw the moraines on Perry Aiken identified by the writer as Early, or Tahoe. These are 1,500' higher and 5 to 6 miles upstream. The canyon in that distance is often narrow, shows no unmistakable signs of glacial erosion or morainal deposits. There is abundant evidence of recent faulting on the alluvial fan and the lower course of Perry Aiken Creek; the fan has nearly disappeared from relative downdropping of the valley side, and a series of transverse

faults can be traced in the bedrock and across the present creek channel for at least 4 miles from the mountain front. In my opinion the "probable moraine" and "ancient till" described by Blackwelder are remnants of alluvium deposited by former courses of Perry Aiken Creek and are found in their present topographic position because of vertical displacement along a series of faults which has exposed granite bedrock previously buried by alluvium.

The lack of clearly defined glacial deposits older than Wisconsin in the White Mountains suggests two alternatives. First, such deposits did exist, but are unrecognizable because of subsequent weathering, erosion, and covering by mass wasting and alluvium. Second, the White Mountains may not have attained sufficient elevation in pre-Wisconsin times to initiate glaciation within the precipitation shadow of the Sierra Nevada.

CHAPTER IV

TOPOGRAPHIC REGIONS

The chief topographic elements of the White Mountain area are the summit upland, the mountain slopes, and the bordering valleys. With regard to these three elements, plus two distinctive areas at the north end of the Range, the area is divided into 9 topographic regions, from north to south and west to east, as follows:

1. Northeast Volcanic Area
2. Boundary Peak-Montgomery Peak Area
3. Summit Upland
4. West Slope
5. Northeast Owens Valley and Owens Valley
6. East Slope
7. Fish Lake Valley
8. Southeast Slope
9. Deep Springs Valley

For boundaries of these 9 regions, see Fig. 56 (p. 104). A summary of the salient topographic features of each region follows.

1. Northeast Volcanic Area

This region at the northern end of the White Mountains is underlain almost entirely by volcanic rock; surface exposures are about equally divided between an older series (late Tertiary) of rhyolites, andesites, tuffs, and breccias, and younger overlying basalts. Its boundaries coincide with the area of volcanics north of Queen Canyon and Trail Canyon shown on the geologic map (Fig. 23, p. 51). Immediately south of Montgomery Pass at the head of Northeast Owens Valley, the west fault

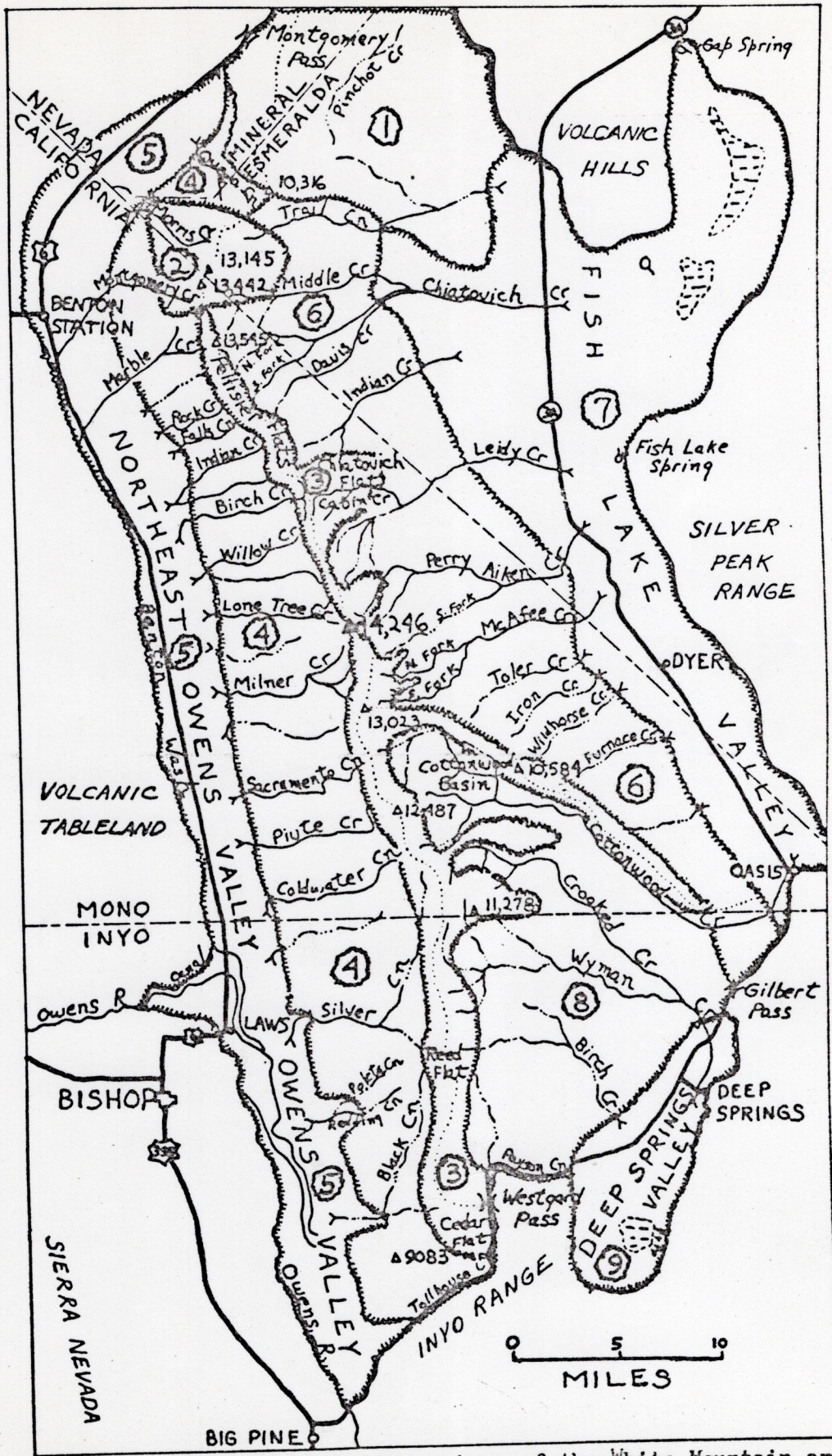

Fig. 56. Map of topographic regions of the White Mountain area. Regional boundaries are indicated by wavy lines; numbers correspond to numbers and geographical names on p. 103.

zone of the White Mountains truncates the lavas in a moderately steep, broken scarp; in the north, east, and south, the slope into other volcanics, alluvium, and metamorphics is predominantly gentle. In the south the volcanics are cut off by a conspicuous northwest-southeast fault zone from Queen Canyon to Trail Canyon. Elevation varies from 10,316' at Mustang Mountain in the south to 5,500' in Fish Lake Valley in the east. There is a square mile of low-relief surface, dipping gently to the northeast, at the top of Mustang Mountain that is very similar in appearance to much of the summit upland farther to the south in the White Mountains. This northeast dip, seldom exceeding 15°, prevails in most of the lavas in the region.

North and east of Mustang Mountain the area is much dissected though relief does not exceed 1,000'. In the acidic volcanics the ravines are numerous, steep-sided, and V-shaped; interfluves are sharp-crested. In the basaltic flows the ravines are far less numerous, steep-sided, but more U-shaped with broader floors filled with blocky detritus; interfluves are the flat-topped surfaces of the flows, which seldom exceed 150' in height. A salient of this region extends southeast into Fish Lake Valley, portions of which are covered by alluvium from Trail Canyon, Middle Creek, Chiatovich Creek, and Davis Creek. Damming of alluvium from Middle Creek and Chiatovich Creek by this salient has forced Trail Creek, much smaller than the other two, into a superposed canyon farther to the northeast. Physiographic evidence indicates Trail Creek once flowed to the southeast after leaving the mountain front. Trail Canyon has the only perennial stream in the region, although springs with short surface flow exist elsewhere, especially in the canyon of Pinchot Creek. (See Fig. 31, p. 65 , for general view of the area.)

2. Boundary Peak-Montgomery Peak Area

South of the fault zone connecting Queen Canyon and Trail Canyon there is a sharp rise of the White Mountain crest (3,000' in 3 miles) to the pyramidal-shaped summits of Boundary Peak (13,145') and Montgomery Peak (13,442') (Fig. 57, p. 107). This small, but distinct, region is defined by the surface exposure of a light-colored granite, termed Boundary Peak granite by Anderson (1937). There are other smaller exposures of Boundary Peak granite farther south along the east slope of the White Mountains but none with such distinctive topographic expression. The distinctiveness arises primarily from a prominent joint pattern with wide-spaced intervals and a nearly vertical dip of the master joints. This results in steep gullies and ravines on the slopes, a series of pinnacles along the ridges (Fig. 58, p.107). To the north and west at the heads of Morris Creek and Montgomery Peak there are fluted, precipitous slopes of 4,000' to 5,000'. No discernible cirque development occurred in these canyons. At the heads of Trail Canyon and Middle Creek to the east cirques do occur, the headwalls of which are only slightly less steep than the west and northwest slopes of the region.

Actually a northeast spur of Montgomery Peak, Boundary Peak rises only 200' from the saddle between the two peaks and would probably not be honored by a specific name were it not for its proximity to the California-Nevada stateline. The von Schmidt Survey of 1872-1873 placed the line between the two states immediately east of Boundary Peak's summit, which was in California. Later surveys proved the line to be in error south of Lake Tahoe; it was moved a half mile west, thus placing Boundary Peak in Nevada. At 13,145 it is the highest point in that state.

The combination of light-colored rock, steep slopes, pyramidal shape of the peaks, and partly isolated position from the remainder of the crest makes this region the most conspicuous of the White Mountain Range when viewed from west, north, or east. (See Fig. 19, p. 41 for view of northwest slopes of this region.)

3. Summit Upland

A 1,200' deep notch separates Montgomery Peak and the north end of Pellisier Flats, from which point the summit upland extends 40 miles south to Westgard Pass with an 18 mile southeast extension from Mt. Barcroft (13,023'). Throughout most of its length it is at least a mile wide; at Chiatovich Flat north of White Mountain Peak and near Blanco Mountain (11,278') south of White Mountain Peak it is 5 miles wide. Along its west margin the summit upland for most of its length slopes moderately downward for 500' to 1,000', then meets the west slope of the Range at a definite break of slope, the angles of which are between 20° and 40°. Its east margin is scalloped by the 2,000' to 3,000' deep cirques of the glaciated canyons in the north and marked by steep-walled canyons in the south and southeast. From north to south along the upland relief does not exceed 1,000', except at its southern end, and is usually much less than that. In the north changes of slope are generally caused by faults; in the south they may be associated with lithology and structure.

The uplift of White Mountain Peak provides a break in the summit upland, though some upland surface is still preserved on its northeastern slope. Just north of this peak, dividing the cirques of Lone Tree Creek and the North Fork of Perry Aiken Creek, is a serrated half mile ridge, the most rugged portion of the entire White Mountain crest. North from this ridge to the northern end of Pellisier Flats, a distance of 13 miles,

the summit upland is remarkably flat (Fig. 59, p. 110). The high point of Pellisier Flats (13,545') is a jointed outcrop of granite rising a mere 25' above its surroundings.

In this northern section of the summit upland the low point of the crest is the 11,200' saddle between Birch Creek and Cabin Creek. This saddle lies along a west-east fault or fault zone. At present the South Fork of Birch Creek and Cabin Creek flow northward for a mile toward the saddle in parallel courses separated by a divide as low as 30'; then each makes a right angle bend at the saddle and flows west and east respectively (Fig. 60, p. 110). Birch Creek has the steeper gradient, will probably eventually capture the headwaters of Cabin Creek. Topographic relationships indicate that the present North Fork and South Fork of Birch Creek once were a part of Cabin Creek's drainage.

North of White Mountain Peak there are two prominent eastward extensions of the summit upland that extend down to 10,000' on their east margins. The larger is Chiatovich Flat between Indian Creek and Leidy Creek, the other, locally called Perry Aiken Flat, lies between Leidy Creek and Perry Aiken Creek. In both cases a series of north trending step faults connects the lower east margins with the main crest on the west; there are no sharp topographic breaks or other surface features which would indicate these two flats were formed at a significantly different time from the main upland. Both flats are traversed by perennial streams; Chiatovich Flat by Cabin Creek, Perry Aiken Flat for a short distance by the north branch of the North Fork of Perry Aiken Creek. These two streams are bigger than adjacent streams flowing at the bottoms of the large, cirque-headed canyons to north and south. Both cut narrow gorges where they leave the flats and descend abruptly 2,500' to the

main canyons, but neither has entrenched its course more than 300' on the upland flats (Fig. 61, p. 112).

South of White Mountain Peak the summit upland is of low relief from the base of the peak to the junction of the two crests at Mount Barcroft (13,023'). The junction area is characterized by the protuberance of isolated outcrops of granodiorite, some of them 100' to 200' above the level of the regolith-covered upland (Fig. 62, p. 112). Similar formations have been called 'tors' in Great Britain. Jointing systems on the White Mountain tors varry in orientation, but are generally wide-spaced with a prominent steeply dipping plane. The tors may be the remnants of the higher portions of the uneven surface of the exposed pluton; of they may result from scattered areas of wider than average joint spacing that have increased resistance to weathering and denudation. Tors at lower elevations are being buried by mass wasting from those above.

The southeast arm of the summit upland is half granite, with 50' to 200' outcrops rising above a generally level surface, and half basaltic flows, with flat tops and steep sides as high as 500' above the granite.

The main summit upland south of Mount Barcroft is underlain almost entirely by sedimentary and metamorphic rock. Its surface is much more diversified than the granitic portions of the upland to the north. From Sheep Mountain (12,487') for 11 miles south to Reed Flat (10,000') there are generally two parallel rows of summits, as much as 1,000' above the intervening valley floors (Fig. 63, p. 113). The west row consists of north-south elongate hills of red to brown Campito sandstone. The east row consists of more conical shaped and more deeply dissected white Reed dolomite.

Fig. 63. South summit upland from the shoulder of Sheep Mountain. At right is Campito Mountain (11,543'), in the center County Line Hill (11,229'), and at left, heavily covered by trees, is Blanco Mountain (11,278'). Campito Mountain and County Line Hill are composed of Campito sandstone, Blanco Mountain of Reed dolomite. Trees in foreground are bristlecone pine (Pinus aristata).

South of Reed Flat, which is a basin of internal drainage and the site of a former shallow lake, the summit upland descends 2,700' in 7 miles to Westgard Pass and Cedar Flat, a 4 mile wide area of north trending flats and ridges up to 750' high. Similar rolling topography continues south into the Inyo Range for many miles without significant break.

South of White Mountain Peak there is no perennial stream along the summit upland except for the headwaters of several east flowing streams, particularly both forks of McAfee Creek. From Reed Flat south the area is especially dry, with no perennial water in the canyons of either west slope or east slope.

The summit upland extends across every major type of lithology in the White Mountains except for the Tertiary rhyolites and andesites. The flattest surfaces are developed upon basalt at lower elevations and close-jointed granite in the upper elevations. Above 12,000' in the flatter areas on weathered granites and metamorphics are occasional exposures of patterned ground. Well-defined polygonal patterns are infrequent. Sorted stripes and non-sorted stripes (classification from Washburn, 1956), the former parallel stony and earthy bands, the latter elongate stripes of fine material rimmed by grasses and sedges, are the most common. No particular attempt was made to determine their origin, though solifluction seems to have altered their primary shape in most areas. Their formation seems to be still active in areas near semi-permanent snowdrifts. Block fields are another feature of local prominence at high elevations on the upland that are independent of lithology. The summit of White Mountain Peak consists largely of quartzite and metavolcanic blocks formed in place, most probably by frost riving.

The question arises whether the summit upland in the White Mountains is the remnant of an old erosion surface now raised to high altitude by

faulting or has been formed in situ by the levelling effect of weathering and denudation at high elevations. In a recent study of New England mountains Thompson (1960-1961) states that the slope break in that region between gentle upland and steep mountainside coincides closely with timberline, and that this is caused by levelling from the much more vigorous frost weathering and resultant creep and solifluction above timberline. He suggests the same relationship prevails in the mountains of western United States, especially the Cascades. In the White Mountains the writer believes that weathering and denudation above timberline have certainly smoothed out irregularities in the initial relief of the summit areas, especially in granites of homogeneous structure and close-spaced joints, but that the summit upland is essentially an old erosion surface of low relief, formed before uplift to its present elevation and only partly modified by subsequent erosional processes. A more important erosional process at present is the reduction of the upland area along its margins by headward advance of west slope and east slope canyons.

The summit upland in the White Mountains dips below timberline, especially in the southeast, without changing its level aspect. Old erosion surfaces have been reported from the summit portions of most of the desert ranges near the White Mountains and from the Sierra Nevada (Nolan, 1943; Hopper, 1947; contain summaries: also Gilbert, 1941, Matthes, 1950b). Most of these surfaces have been dated as late Pliocene or early Pleistocene. The assumption is strong that during that time a widespread surface of low to moderate relief existed in the southwestern Great Basin, of which the White Mountain summit upland is an upfaulted remnant.

Another question is whether the surfaces of the summit upland at various levels represent the dislocated parts of a single surface or have been formed during periods of sufficient tectonic quiescence to be designated

as specific erosion surfaces. In my opinion, the White Mountain summit upland is basically one surface, much dissected by faults along which movement has varied in time and magnitude in very short distances. Any enumeration of multiple erosion surfaces holds good only for limited areas of the Range.

4. West Slope

This region extends from just below Montgomery Pass in the north to the southwest tip of the area, a distance of 55 miles. Its western margin is the break of slope with Northeast Owens Valley and Owens Valley, its eastern border the summit upland and the volcanics and Boundary Peak granite of Region I and Region II. Its predominant and most spectacular topographic feature is the uniformly steep slope of 6,000' to nearly 10,000' from the California-Nevada stateline to White Mountain Peak. This is one of the most impressive, though little publicized, mountain walls in the United States. The most precipitous segment of this slope is the Rock Creek-Falls Canyon area west of Pellisier Flats (Fig. 64, p. 117).

Falls Canyon derives its name from a series of high angle cataracts and free-leaping falls, several over 100' in height. The next two canyons north also have many cataracts and falls. All of these are in granite; farther to the south from Birch Creek to Milner Creek, lesser cataracts and a few falls occur in red quartzite. Despite steep gradients in this quartzite, as much as 1,500' per mile, streams are oriented along zones of weakness, such as bedding planes and joint planes, and take winding courses down through it.

From its north end to Indian Creek the west slope is one main scarp. From that point to its southern extremity the west slope is characterized by a succession of northwest-southeast faults that pass

from valley to mountains at angles of 15° to 20° with the principal alignment of the mountain front. These faults are often expressed topographically by minor scarps in the mountains and by scarplets in the alluvium. The conspicuous straightness of the foot of the west slope is offset for short distances where the mountain front follows this northwest-southeast fault system.

South of White Mountain Peak the west slope becomes progressively less steep toward the south, though still rising 5,000' to 6,000' above the valley. At the southern end the mountain front is indented at the canyon mouths, and the apices of old, dissected alluvial fans extend far back into the canyons, as much as 2,500' above the floor of Owens Valley (Fig. 65, p. 117).

Streams in the northern two-thirds of the region flow from east to west in narrow V-shaped canyons; in the southern third Silver Canyon and Black Canyon have northeast-southwest upper courses, canyon floors are much wider, and lower Silver Canyon has the only important surface flow.

5. Northeast Owens Valley and Owens Valley

This one valley, structurally, borders the west slope of the White Mountains from the foot of Montgomery Pass at 6,600' to 3,900' at the southwest tip of the area. All but 200' of this drop in elevation occurs in Northeast Owens Valley, north of the settlement of Laws. The western border of Northeast Owens Valley displays a remarkably parallel alignment to the front of the White Mountains, even in the eastward swing at the northern end of the Range. This suggests some structural control by the massive White Mountain uplift.

The axial drainage of Northeast Owens Valley, perennial for only a short distance below Montgomery Creek and Marble Creek, is pushed to its

west margin for nearly all of its course by the alluvial fans from the White Mountains. Three of these fans--Marble Creek, Milner Creek, and Coldwater Canyon--extend completely across the valley and divide it into three subdivisions: from north to south, Benton Valley, Hammil Valley, and Chalfant Valley, each of which formerly contained shallow lakes up to three miles in length. Lake and fluvial deposits in these three valleys have resulted in flat floors; thus there is a three-step aspect to the descent of Northeast Owens Valley to the Owens River, the largest step being 500' below Marble Creek. There are small outcrops of lava in the valley protruding above the alluvium, especially at the toes of the three fans extending across the valley. Burying of salients of lava by these three particular fans could be a reason why they reached across the valley. All three, however, have drainage basins larger than those of immediately adjacent canyons along the west slope.

Although alluvium from the Sierra Nevada has pushed the Owens River over to the east side of its valley, alluvial fans from the White Mountains do not reach the river, which is bordered on the east by a flat, half-mile to one mile strip. The Owens River with a gradient of 10' per mile or less has a meandering course, which extends 60 miles south of the White Mountains area. All discernible former beach lines of Owens Lake are south of the White Mountains, although the 20 mile stretch of river within the area is bordered by low sand dunes.

From Sacramento Canyon south the alluvial fans along the east margin of the valley are marked by many recent fault scarps, some of which face the mountains. Some of these result from small, relatively downfaulted, troughs across the fans; others, such as at the mouth of Redding Canyon, are caused by the tilting of small blocks more steeply to the west than on adjacent blocks closer to the mountain front (Fig. 65, p. 117).

6. East Slope

Although less steep than the northern half of the west slope, the east slope still rises 6,000' to 9,000' above Fish Lake in all but its southern end. The most distinctive topographic feature is the development of cirques at the heads of the glaciated canyons. These vary in width at their crests from three miles at Indian Creek to a half mile at the head of both forks of McAfee Creek. Headwalls are as much as 3,000' in the south branch of the North Fork of Perry Aiken Creek. Those canyons glaciated during the Late substage have a less eroded appearance than those glaciated only during the Early and Middle substages. In the southern portions of the cirques of both forks of Chiatovich Creek and Davis Creek, smaller, 500' to 1,000' deep cirques have been developed, probably contemporaneously with the last glacial substage (Fig. 66, p.121).

The break of slope between the summit upland and the east slope is generally sharp, 20° to 30°, and is fretted by nivation depressions as far south as Iron Creek. When seen from Fish Lake Valley in early summer, this break of slope is clearly etched on the skyline by a series of snowdrifts in these nivation hollows.

The fault zone of the valley margin of the east slope is more complex than that of the west slope. Displacement has occurred along a series of faults, and there are no massive scarps comparable to that of the Falls Canyon area. A similar relationship prevails to the west slope in that a northwest-southeast fault system intercepts at acute angles a north-south system. However, on the east slope the mountain front is determined chiefly by orientation along the northwest-southeast system. Where the front does swing to the north for short distances, the northwest-southeast faults can generally be traced for some miles into the bedrock of the mountains.

From McAfee Creek north the east slope canyons are U-shaped and contain perennial streams, the largest in the Range. South of McAfee Creek, the canyons are V-shaped and have intermittent streams; surface flow is usually confined to the middle third of the longitudinal stream course. From McAfee Creek north there are 7 major canyons draining the east slope, as compared with 14 in the similar interval along the west slope. The U-shape of these 7 canyons is caused in part at upper elevations by glaciation; at lower elevations it results primarily from alluviation of the canyon floors. Below 8,000' there are few areas where the streams have cut channels in bedrock. Depth of alluvial fill within the canyons is unknown; projections of slopes at the mouth of Chiatovich Creek indicate a depth of at least 400'.

At present most of this alluviation seems to be taking place from debris flow deposits (Fig. 67, p. 123). The gradients of these east slope canyons are not steep enough for movement of debris flows out of the mountains onto the alluvial fans, except under rare conditions when intense rainstorms may strike the mountain front area.

Prominent alluvial terraces exist in all the east slope canyons below 8,000'. Terrace remnants are found as much as 500' above the present stream in Middle Canyon, but in general the well-developed terraces are 25' to 50' above present stream levels. At lower elevations multiple terraces exist, which in most cases can be traced to recent faults at the mountain front or across the alluvial fans. At upper elevations one major alluvial terrace descends from the lowest moraines; a similar terrace occurs in the non-glaciated canyons, indicating that the causes of alluviation in the canyon are generally climatic and physiographic, not just result of outwash from glacial deposits.

At high elevations in the glaciated portion of the east slope, the interfluves are a part of the low relief summit upland. Below the break of slope they are sharp-crested and steep-sided down to Fish Lake Valley. In the southern, non-glaciated part of the east slope the ridges are also steep and narrow from the summit upland to the valley.

7. Fish Lake Valley

Forty-four miles of this valley, all but 10 miles of its narrow southern tip, are included in this region. Maximum width is 20 miles in the north. Elevation of the valley floor ranges from 5,000' near Oasis in the south to 4,800' at Gap Spring in the north. The west and east sides of the valley are much different in appearance. The White Mountain front on the west is higher, steeper, and straighter than the sinuous front of the Silver Peak Range on the east. The alluvial fans from the White Mountains are much larger and push the south to north axial drainage over to the east edge of the valley. The gradient of this drainage, called Fish Lake Valley Wash, is only about 5' per mile; thus the valley floor has a level appearance. Along this drainage for 10 miles north of the mouth of McAfee Creek extends a marshy area, a half mile in width. Midway along the eastern border of this marsh is a 300' by 100' pond of slightly warm and brackish water, Fish Lake Spring. From this pond, which evidently contained native fish, probably a species of minnow (Siphateles), the valley received its name.

In the northeast arm of the valley is a 10 mile long, linear-shaped salina, divided into two segments by an alluvial fan from the Silver Peak Range. The northern segment contains surface water in the winter and spring of wet years. For a brief period from 1885 to 1886, borax was mined commercially from this salina. The northeast end of Fish Lake

Valley is an almost imperceptible low alluvial divide between 300' lava flows. Gap Spring is situated on the divide; in very wet years the discharge flows north toward Columbus Salt Marsh.

As discussed previously under drainage in Chapter III, beach lines in Fish Lake Valley indicate a former lake which stood at an elevation just above 4,800' and overflowed into Columbus Salt Marsh. Since the floor of that marsh is 200' lower than the outlet of Fish Lake Valley and occupies an extensive topographic basin, the formation of a very large Pleistocene lake would have been necessary to build beach lines higher than 4,800' in Fish Lake Valley. None has been certainly identified by the writer. There are also no discernible terraces in the lava at the Gap Spring outlet. The 4,800' level lake of Wisconsin time extended as far south in the valley as the mouth of McAfee Creek.

In the northwestern edge of the valley, Middle Creek, Chiatovich Creek, and Davis Creek have built a compound alluvial fan that is the largest in the White Mountain area. At the mountain front, it stands 2,000' above the valley floor and it has a maximum radius of 7 miles. Southward the fans rapidly dimihish in size until they nearly disappear at Perry Aiken Creek, because of faulting (Fig. 68, p. 123). Recent faulting is general on all Fish Lake Valley fans on both east and west margins, but number of faults and vertical displacement are much greater from Perry Aiken Creek south. From Wildhorse Creek south to Cottonwood Creek, a distance of 12 miles, there is a conspicuous and nearly continuous fault in the alluvium a mile east of and parallel to the mountain front. Wildhorse Creek and Furnace Creek have cut very steep 500' gorges at their mouths through step-faulted scarps in alluvium and bedrock.

8. Southeast Slope

This region lies between the two branches of the southern summit upland. Cottonwood Creek cuts off the southeast tip of the upland and flows into Fish Lake Valley; all other drainage is into Deep Springs Valley. The only perennial stream entering Deep Springs Valley is Wyman Creek; its chief tributary, Crooked Creek, often goes dry just above its junction with Wyman Creek.

The region, though much dissected to relief of 500' to 1,000', is the most gentle slope of the White Mountains. Stream gradients are from 300' to 500' per mile. At the northern end of the area is Cottonwood Basin, enclosed on the west by 1,000' cliffs of Reed dolomite, on the north and east by 500' to 1,000' rises of granite and basalt. The floor of the basin slopes to the southeast from 11,000' to 9,000' in 6 miles. The basin is characterized by numerous, steep-sided granite knobs and pinnacles (Fig. 69, p. 127). Individual pinnacles may be 100' high, clusters of them may rise 500' above local base level. Well-developed joint planes of different orientations in this porphyritic granite permit deep weathering. The joints are often wide-spaced, 6' or more, and there are very few blocks or boulders of intermediate size (Fig. 70, p. 128). The bases of the pinnacles are surrounded by granitic sand that often fills the intervening areas and results in many small-dimensioned flats. The general appearance of the topography is very similar to that of the much photographed Alabama Hills at the east base of Mount Whitney in southern Owens Valley.

The same type of granite exposed in Cottonwood Basin underlies most of the eastern half of this region, and this knob and pinnacle topography continues 18 miles south to the northwest edge of Deep Springs Valley. Stream courses through the granite are narrow-floored and tortuous,

especially along Crooked Creek; hence, the name. The canyons of Cottonwood Creek and Crooked Creek are 500' to 1,000' deep. The ridge between the two streams is broad, and relatively level where covered by basalt.

Sedimentary and metamorphic rock underlie most of the western half of the region. Canyons are 500' to 1,000' with steep sides and sharp-crested ridges.

9. Deep Springs Valley

This northeast trending, oval valley, 12 miles long with a maximum width of 5 miles, is a striking example of an enclosed desert basin (Fig. 71, p. 130). It is completely surrounded by mountains rising 1,000' to 4,000' above its floor. All of its boundaries are clearly defined fault zones, with some remarkably well-preserved fault scarps, especially along the southeastern edge above the salina of Deep Springs Lake. Here precipitous triangular spurs, separated by short, very steep canyons with practically no alluvial fans, rise 2,000' directly above the valley floor. The unweathered nature of the scarp gives the impression that it represents the actual fault face. At the north end of the valley at Piper Mountain (7,703') lava beds at the top and west base of the mountain, originally part of a single field, have been dislocated vertically by faulting to a maximum of 1,500'. The fault scarps along the western edge of the valleys are of lesser magnitude, but still very fresh appearing. Faulting in granite near the mouth of Wyman Creek has forced the stream to cut a two mile gorge, with nearly vertical 200' walls and a 15' to 20' wide floor.

Miller (1928, pp. 523-524) postulated that alluvial boulders of quartzite and rhyolite at 6,300' to 6,900' on top of the northeast ridge of Deep Springs Valley marked former courses of Wyman Creek, which once flowed southeastward into Eureka Valley, but was forced to turn southwest

into a developing Deep Springs basin bacause of relative uplift of this ridge. This change of course by Wyman Creek may have occurred, but the alluvial boulders to which Miller alludes are exposed over a wide area west, south, and east of this ridge. They could not all have been deposited by former channels of Wyman Creek.

The floor of Deep Springs Valley slopes 500' to the salina in 10 miles. Wyman Creek has a narrow, inconspicuous alluvial fan for 6 miles of that length. Two sets of old beach lines at 4,960' and 5,020' indicate the valley floor was occupied by a lake at least 5.5 miles long in the late Pleistocene or perhaps in much more recent times. At present Deep Springs Lake, though wet at its surface, has only intermittent standing water. During World War I there was some commercial exploitation of its saline deposits. The series of springs immediately southeast of the lake are slightly warm and brackish; no accurate flow measurements exist, but part of the flow is used to irrigate pasture adjacent to the lake.

CHAPTER V

BIOTA

The great diversity of plant and animal life in the White Mountain area reflects the wide range in climate, geology, and topography. All the life zones, from Lower Sonoran to Arctic-Alpine, are found within the region. Over a period of 14 years the writer has collected or identified in the field some 500 native species or subspecies of flowering plants, and about 185 native species of vertebrate animals, including 5 species of amphibians, 20 of reptiles, 120 of birds, and 40 of mammals. The following discussion of White Mountain biota is confined largely to the flora, with some reference to the fauna.

Decrease of temperature and increase of precipitation with rise in elevation are in general the most important environmental influences upon the biota in the White Mountain area. The region is thus divided arbitrarily into 4 zones, the boundaries of which are drawn on a floristic basis and are correlated primarily with altitude. From valley floor to mountain crest the 4 zones are:

1. Desert Shrub, 4,000' to 6,500'
2. Pinyon-Juniper, 6,500' to 9,000'
3. Upper Pine, 9,000' to 11,500'
4. Alpine, above 11,500'

Each zone is characterized by a typical life form or an assemblage of dominant tree species. Trees, where present, are stressed over herbs as zone indicators, because they are more widely known, are more readily seen and identified, have more effect on the microhabitat, and have, in most instances, a more restricted altitudinal range. Elevation figures

for the limits of the respective zones are averages; slope and exposure will cause fluctuations that seldom exceed 500'. At any one location in the area the boundaries may be indistinct or lacking, but in general they are discernible. The zonal elevations do not differ significantly between the west slope and east slope of the White Mountains, although vegetation is more luxuriant on the upper portion of the east slope. Differences in zonal elevations vary more from exposure within a given canyon, for example, whether north-facing or south-facing, than from position on either west slope or east slope of the Range. Climate exerts by far the greatest control over distribution of plants within the zones, but local edaphic factors, such as the nature of the bedrock, the presence of surface water, and the percentage of soil alkalinity, give rise to distinct plant associations within the general climatic matrix of the zone. This, in turn, affects animal distributions.

Tables VI, VII, VIII, and IX list characteristic plants and mammals of each of the four zones. The range of no two species coincides exactly, and there is much zonal overlap of species other than the indicators. Some species are important components of more than one zone and thus are listed in more than one table.

Desert Shrub Zone. 4,000' to 6,500'. (Table VI, p. 134.)

This zone extends from the floor of the valleys to the lower limit of tree growth away from watercourses. This lower, or dry timberline, occurs from 6,000' to 6,500'; seldom is there more than sporadic appearance of trees, pinyon pine (Pinus monophylla) and juniper (Juniperus osteosperma), below 6,500'. The most distinctive feature of the zone is the great expanse of small-leaved, often thorny, shrubby vegetation. The shrubs are low in stature, rarely more than 5', and usually gray-green to dull brown in color (Fig. 72, p. 135). Most are members of the Chenopodiaceae

TABLE VI

Characteristic Plants and Mammals in the Desert Shrub Zone

TREES

Populus Fremontii (cottonwood)
P. trichocarpa (cottonwood)
Salix spp., esp. exigua, lasiolepis, laevigata (willow)

SHRUBS

Artemisia spinescens (bud sage)
A. tridentata (sagebrush)
Atriplex canescens
A. confertifolia (shadscale)
Chrysothamnus nauseosus ssp. (rabbitbrush)
C. teretifolius
Dalea Fremontii Saundersii
Ephedra nevadensis (squaw tea)
Eurotia lanata (winter fat)
Grayia spinosa (hop sage)
Hymenoclea salsola
Prunus Andersonii (desert peach)
Sarcobatus vermiculatus (greasewood)
Tetradymia glabrata (horse brush)
T. axillaris (cotton thorn)

HERBS

Allenrolfea occidentalis
Anemopsis californica
Calochortus Kennedyi
Chaenactis Xantiana
Cryptantha circumscissa
Eriogonum deflexum
E. inflatum (desert trumpet)
E. nidularium
Gilia leptomeria
Hermidium alipes
Langloisia punctata
Layia glandulosa
Lupinus flavoculatus
Mentzelia albicaulis

HERBS (continued)

Opuntia basilaris (beaver tail)
O. echinocarpa (cholla)
Oxytheca perfoliata
Phacelia Fremontii
Sphaeralcea ambigua monticola (desert mallow)
Stanleya pinnata
Suaeda Torreyana ramosissima

GRASSES, RUSHES, and SEDGES

Carex spp. (sedge)
Distichles spicata stricta (salt grass)
Elymus triticoides
Hilaria Jamesii (galleta)
Orysopsis hymenaides (ricegrass)
Phragmites communis (reed)
Scirpus spp. (tule)
Sporobolus airoides (sacaton)
Stipa speciosa

MAMMALS

Citellus leucurus (white-tailed antelope ground squirrel)
Dipodomys microps (kangaroo rat)
Lepus californicus (black-tailed jackrabbit)
Neotoma lepida (wood rat)
Peromyscus maniculatus (deermouse)
Vulpes macrotis (kit fox)

or the Compositae.

In the lower part of the zone the dominant shrub is shadscale (Atriplex confertifolia). Above 5,500', except on some of the alluvial fans, sagebrush (Artemisia tridentata) is dominant. In popular terminology the whole complex of shrubs of many species is indiscriminately called 'sagebrush.' In this chapter the term is reserved for the species Artemisia tridentata. Sagebrush has higher soil moisture requirements than shadscale and is also found on moist, alkali-free sites below 5,500'. In addition to these two dominants there are a dozen other common shrubs and another 20 which occur frequently. At all places in the shrubby areas, however, the amount of bare ground exceeds plant cover; shadscale seldom covers more than 10% of the ground.

Herbaceous growth between the shrubs is generally sparse, but on occasional years there is a profuse germination and maturation of annuals. Went (1955) studied this phenomenon in Southern California deserts, tested many desert annual seeds in the laboratory, and reached the following conclusions: a heavy rain, preferably an inch or more, is necessary in the period from October through December to leach out water-soluble germination inhibitors in seed coats; once the seeds are primed by such a rain, they will germinate the next spring and more than half of thos germinating will survive, flower, and set seed. In the White Mountain area there were lavish blooms of annuals in the desert shrub zone in the years 1952, 1956, and 1958. In all of these seasons there were substantial, widespread rains during the October-December period, also in the following spring. In 1962 when seasonal precipitation totals throughout the area were well above normal, fall and early winter rains in the valley regions were minor, and the resulting spring bloom of annuals was of much smaller scope. Thus, the general framework of Went's conclusions appears to be verified for

desert annuals in the White Mountain area, at least during the past decade. Some annuals, however, particularly Lessingia germanorum Lemmonii and several species of Eriogonum, germinate and mature after receiving moisture at any time of the growing season. Common genera producing annuals during favorable seasons are Chaenactis, Cryptantha, Eriogonum, Gilia, Mentzelia, Oenothera, and Phacelia. Wet years, regardless of the timing, are reflected in the vigorous growth of the perennials, both herbaceous and shrubby (Fig. 73, p. 138).

Some species of shrubs produce many stems at or even below the soil level. This system of branching accumulates a mound of wind-blown soil and debris above the general soil level. Some herbaceous species grow only in these built-up soils under shrubs, others are found only in the open spaces between shrubs.

Local edaphic communities embedded in this matrix of desert shrubs are those in saline areas and those along perennial surface water. Plants with a high alkali tolerance, chiefly grasses and Chenopodiaceae, grow on the fringes of and sometimes well into the saline deposits of the valleys (Fig. 74, p.138). Chief grasses of this habitat are saltgrass (Distichlis spicata stricta) and sacaton (Sporobolus airoides). They grow generally on the edges of alkaline areas and provide important forage in spring and fall for domestic stock. Main chenopods are Allenrolfea occidentalis, Sueda Torreyana ramoissima, and greasewood (Sarcobatus vermiculatus).

Riparian vegetation in this zone, especially along the meandering Owens River, is often dense. Dominants are reeds (Phragmites communis), tules (Scirpus spp.), cottonwoods (Populus spp.), and willows (Salix spp.). In autumn cottonwoods and willows, along with rabbitbrush (Chrysothamnus spp.), present a welcome display of color in what is usually a drab

vegetational landscape most of the year (Fig. 75, p. 140).

Because of its warm summers this zone has most of the population of amphibians and reptiles in the White Mountain area. Most noteworthy reptiles in terms of human attention are 3 species of rattlesnakes, Crotalus viridis, C. Mitchelli, and C. cerastes (sidewinder). None of the three are numerous. There are more species of mammals in this zone than in any of the others, particularly small nocturnal rodents of the genera Dipodomys, Microdipodops, Perognathus, and Peromyscus. Near cultivated areas the black-tailed jackrabbit (Lepus californicus) builds up large populations, perhaps cyclic, and causes important damage to pasture and alfalfa fields. A significant portion of the cost of planting a new alfalfa field is proper fence protection against the inroads of jackrabbits.

Pinyon-Juniper Zone. 6,500' to 9,000'. (Table VII, p. 141 .)

This zone of open woodland is delineated by the range in elevation of the pinyon pine (Pinus monophylla). The juniper (Juniperus osteosperma) is an important tree of this zone in many other Great Basin ranges but is significant in the White Mountains only at the southern end near Cedar Flat (the name is derived from a common name for the juniper), at the northern end at Montgomery Pass, and at several stations on the east slope on metamorphic rock. Juniper seldom occurs on granite. Where the two trees are found together, the pinyon extends to higher elevations.

Except for the wide use of the name pinyon-juniper for similar zones on other Great Basin Ranges, this zone in the White Mountains might well be called pinyon-sagebrush. Sagebrush is by far the most common shrub, often occurring in nearly pure stands in flats as well as being the chief understory amongst the pinyons. On disturbed ground

TABLE VII

Characteristic Plants and Mammals
in the Pinyon-Juniper Zone

TREES

Betula fontinalis (water birch)
Cercocarpus ledifolius (mountain mahogany)
Juniperus osteosperma (Utah juniper)
Pinus monophylla (pinyon pine)
Populus tremuloides (aspen)
P. trichocarpa (cottonwood)
Salix spp., esp. lasiolepis, lutea
Shepherdia argentea (buffalo-berry)

SHRUBS

Artemisia tridentata (sagebrush)
Chrysothamnus nauseosus consimilis (rabbitbrush)
C. n. viscosus (rabbitbrush)
C. viscidiflorus puberulus
C. v. pumilus
Ephedra viridis (Mormon tea)
Holodiscus microphyllus (cream bush)
Peraphyllum ramosissimum
Purshia glandulosa (bitterbrush)
P. tridentata (bitterbrush)
Symphoricarpos longiflorus (snowberry)

HERBS

Achillea lanulosa (yarrow)
Astragalus oophorus
Chaenactis Douglasii rubricaulis
Erigeron aphanactis
Eriogonum caespitosum
E. cernuum
E. microthecum
E. racemosum
E. umbellatum
Haplopappus acaulis
Lygodesmia spinosa
Lupinus caudatus
Machaeranthera canescens
Nicotiana attenuata (tobacco)

HERBS (continued)

Opuntia erinacea (prickly pear)
Penstemon floridus
Phlox Stansburyi
Plagiobothrys Kingii
Potentilla pectinisecta
Rosa Woodsii ultramontana (wildrose)
Senecio multilobatus
Stellaria longipes
Trifolium Wormskioldii

GRASSES, RUSHES, and SEDGES

Carex spp., esp. nebraskensis (sedge)
Elymus cinereus
Hesperochloa Kingii
Juncus balticus (rush)
Koeleria cristata (junegrass)
Melica bulbosa
Muhlenbergia filiformis
Oryzopsis hymenoides (ricegrass)
Poa incurva
P. pratensis (Kentucky bluegrass)
Sitanion Hystrix
Stipa californica
S. comata

MAMMALS

Eutamias panamintinus (Panamint chipmunk)
Lagurus curtatus (sagebrush mouse)
Peromyscus maniculatus (deermouse)
Spilogale gracilis (spotted skunk)
Sylvilagus nuttallii (mountain cottontail)
Thomomys talpoides (pocket gopher)

or on moist sites Chrysothamnus nauseosus ssp. is abundant. Two closely related species of bitterbrush (Purshia glandulosa and P. tridentata) are important browse species for deer and livestock.

Within this zone on the west slope of White Mountain Peak in the drainages of Milner Creek and Lone Tree Creek at elevations of 7,000' to 8,000' occur scattered stands of Jeffrey pine (Pinus Jeffreyi). The trees are stunted, with broken, ragged crowns, and reproduction is light. No trees of this species have been identified on the east slope.

When growing on deep alluvial slopes, especially on those derived from granite, the pinyon is usually a conical tree, less than 15' tall, with a simple trunk. On shallow alluvium or bedrock, especially on sedimentary or metamorphic rock, the pinyon is a large, spreading tree, up to 40' high, with a much branched trunk. On the floors of canyons and flats at low elevations in this zone, the pinyon is often absent or represented only by a few small trees. In the Virginia Range near Reno, Nevada, Billings (1954) noted that pinyon growth was restricted to the slopes and suggested the chief reason may be a sharp temperature inversion caused by cold air drainage in the canyons. Though cold air drainage may be a factor in restricting pinyon growth on canyon floors in the White Mountains, it seems probable to the writer that a more important factor is the loss of soil moisture through deep, porous alluvium. Above 7,500' in the east slope canyons of the White Mountains pinyon growth is by no means confined to the slopes; it is often profuse on the canyon floors, though the trees are frequently small. Precipitation above 7,500' may be sufficient to offset loss of soil moisture.

The edible nut of the pinyon was a food staple of the Piutes who inhabited the area at the coming of the white man in 1861. At present,

it is harvested in minor quantity, mostly by Piutes, for local food consumption and for sale in Owens Valley markets. There is an enormous fluctuation of yield from year to year. Good yields seem to be correlated with high precipitation, especially during the spring. In the years 1959 through 1961 almost no pinyon nuts matured in the White Mountains.

Stream courses in this zone are often lined by a dense growth of willows (Salix spp.), cottonwood (Populus trichocarpa), buffalo-berry (Shepherdia argentea), water birch (Betula fontinalis), aspen (Populus tremuloides), and wildrose (Rosa Woodsii ultramontana). Along streams of the eastern slope there are occasional border strips, as wide as 200 yards, of open meadow (Fig. 76, p.144). Important meadow species are sedges (Carex spp.), rushes (Juncus spp.), and Kentucky bluegrass (Poa pratensis).

The upper limit of growth of pinyons is much less clearly defined than the lower, and the boundary of this zone with the upper pine zone is often indistinct, with much interfingering between the two zones. Frequently, a gap of 500' to 1,000' exists between pinyon trees and the higher pines. In many areas this gap is filled by mountain mahogany (Cercocarpus ledifolius) or aspen (Populus tremuloides). Mountain mahogany, often shrublike in habit, extends up to 10,000' or more on south-facing slopes (Fig. 77, p. 144). Adjacent north-facing slopes often support a growth of pine. Away from stream courses aspen grows chiefly on north-facing slopes where mass movement of weathered bedrock has been active. In some Great Basin ranges mountain mahogany and aspen constitute a distinct zone, but their growth is too patchy to be considered as such in the White Mountains.

3. Upper Pine Zone. 9,000' to 11,500'. (Table VIII, p.146 .)

This zone is characterized by open forests of pine and many broad upland expanses of low shrubs, chiefly sagebrush, little sagebrush (Artemisia arbuscula nova), and (Chrysothamnus viscidiflorus pumilus). Bristlecone pine (Pinus aristata) and limber pine (P. flexilis) are the chief species of the pine forest, which occupies less than half of the zone. The pine forest is largely, though not entirely, restricted to north-facing and east-facing slopes.

On outcrops of dolomite or limestone bristlecone pine is the dominant, often the only tree. Its greatest concentration is south of White Mountain Peak on exposures of Reed dolomite from the head of Cottonwood Creek to Reed Flat, a distance of 16 miles (Fig. 78, p. 147). Immediately east of Reed Flat occur most of the 17 trees which Schulman (1958), from tree ring analysis, found to be 4,000 years old or more (Fig. 79, p.147). The species, whose range extends eastward through Nevada into Utah and western Colorado, reaches its largest size in the White Mountains. On the east shoulder of Sheep Mountain at an elevation of 11,300' the 'Patriarch' bristlecone measures 37' in circumference 4' above the ground (Fig. 80, p. 148).

From White Mountain Peak north to Queen Canyon the bristlecone pine occurs at scattered locations, most commonly on dolomite or limestone, but also on granite and lava. On the latter outcrops limber pine is nearly always the dominant tree, the bristlecone being restricted to steep bedrock slopes, or windswept areas near timberline. In the zone as a whole limber pine is the more abundant tree and its reproduction is more vigorous. North of White Mountain Peak on north and east exposures it occurs in fairly dense stands which include a few interspersed bristlecones (Fig. 81, p. 149).

TABLE VIII

Characteristic Plants and Mammals
in the Upper Pine Zone

TREES

Cercocarpus ledifolius (mountain mahogany)
Pinus aristata (bristlecone pine)
P. flexilis (limber pine)
P. Murrayana (lodgepole pine)
Populus tremuloides (aspen)
Salix spp., esp. geyeriana, orestera (willow)

SHRUBS

Artemisia arbuscula nova
A. Rothrockii
A. tridentata (sagebrush)
Chamaebatiaria millefolia (desert sweet)
Chrysothamnus Parryi vulcanicus
Haplopappus Macronema
H. suffruticosus
Leptodactylon pungens
Linanthus Nuttallii
Potentilla fruticosa
Purshia tridentata (bitterbrush)
Ribes cereum (currant)

HERBS

Arenaria Kingii
Astragalus Whitneyi
Castilleja Applegatei (paint brush)
Crepis intermedia
Dodecatheon redolens (shooting star)
Epilobium brevistylum
Erigeron Clokeyi
Eriogonum latens
E. microthecum
E. umbellatum
Eriophyllum lanatum monoense
Erysimum perenne
Hymenoxys Cooperi canescens
Ipomopsis congesta montana
Linum Lewisii (flax)
Lupinus argenteus tenellus
Mertensia ciliata stomatechoides (bluebells)

HERBS (continued)

Mimulus primuloides
Monardella odoratissima pallida (pennyroyal)
Phacelia frigida
Rumex pauciflorus
Senecio spartioides
Sphenosciadium capitellatum
Trifolium micranthum
T. monoense

GRASSES, RUSHES, and SEDGES

Agropyron trachycaulum
Bromus Porteri
Carex spp., esp. Douglasii (sedge)
Deschampsia caespitosa
Elymus cinereus
Hordeum brachyantherum
Juncus balticus (rush)
Koeleria cristata (junegrass)
Muhlenbergia Richardsonis
Oryzopsis hymenoides (ricegrass)
Poa incurva
P. pratensis (Kentucky bluegrass)
Sitanion Hystrix
Stipa pinetorum

MAMMALS

Citellus lateralis (golden-mantled ground squirrel)
Erethizon dorsatum (porcupine)
Eutamias quadrivittatus (Colorado chipmunk)
Lepus townsendii (white-tailed jackrabbit)
Peromyscus maniculatus (deermouse)
Taxidea taxus (badger)

Lodgepole pine (Pinus Murrayana) occurs at several sites north of White Mountain Peak. A nearly pure stand of about 200 acres is situated on a north-facing slope overlooking Cabin Creek on Chiatovich Flat at elevations of 10,200' to 10,500' (Fig. 82, p. 149).

In both this zone and in the pinyon-juniper zone fire is of minimal importance. Occasional trees may burn after being struck by lightning. But the wide spacing of trees and shrubs and the lack of a continuous organic ground cover make the spread of fire most unlikely. Actually, in recent years, the only fires involving more than just a few trees have spread along the crowns of willows and cottonwoods in stream-bank habitats.

Vegetation is much less dense along stream courses in this zone than in the lower zones. Willows, chiefly Salix Geyeriana, and aspen are the main trees. Stringer meadows of sedges and grasses border the streams in areas of gentle slope.

Away from streams in level regions of well-comminuted soil are many small areas of dry meadowland, characterized by Carex Douglasii, Juncus balticus, and several grasses. Koeleria cristata, Oryzopsis hymenoides, Poa incurva, and Sitanion Hystrix are important bunchgrasses in this zone. Lupinus argenteus tenellus is a conspicuous herb.

The upper limit of this zone is determined by timberline, usually between 11,000' and 11,500', though a few scrub trees reach nearly to 12,000' along ridges. Timberline is generally slightly higher on the east slope than on the west, probably the result of more protection from wind. At timberline limber pine is much more likely to assume dwarf or prostrate forms than bristlecone pine (Fig. 83 and Fig. 84, p. 151). Fig. 85 (p. 152) shows the woodland and forest areas of the White Mountains between the lower timberline of the pinyon-juniper belt and the upper timberline of

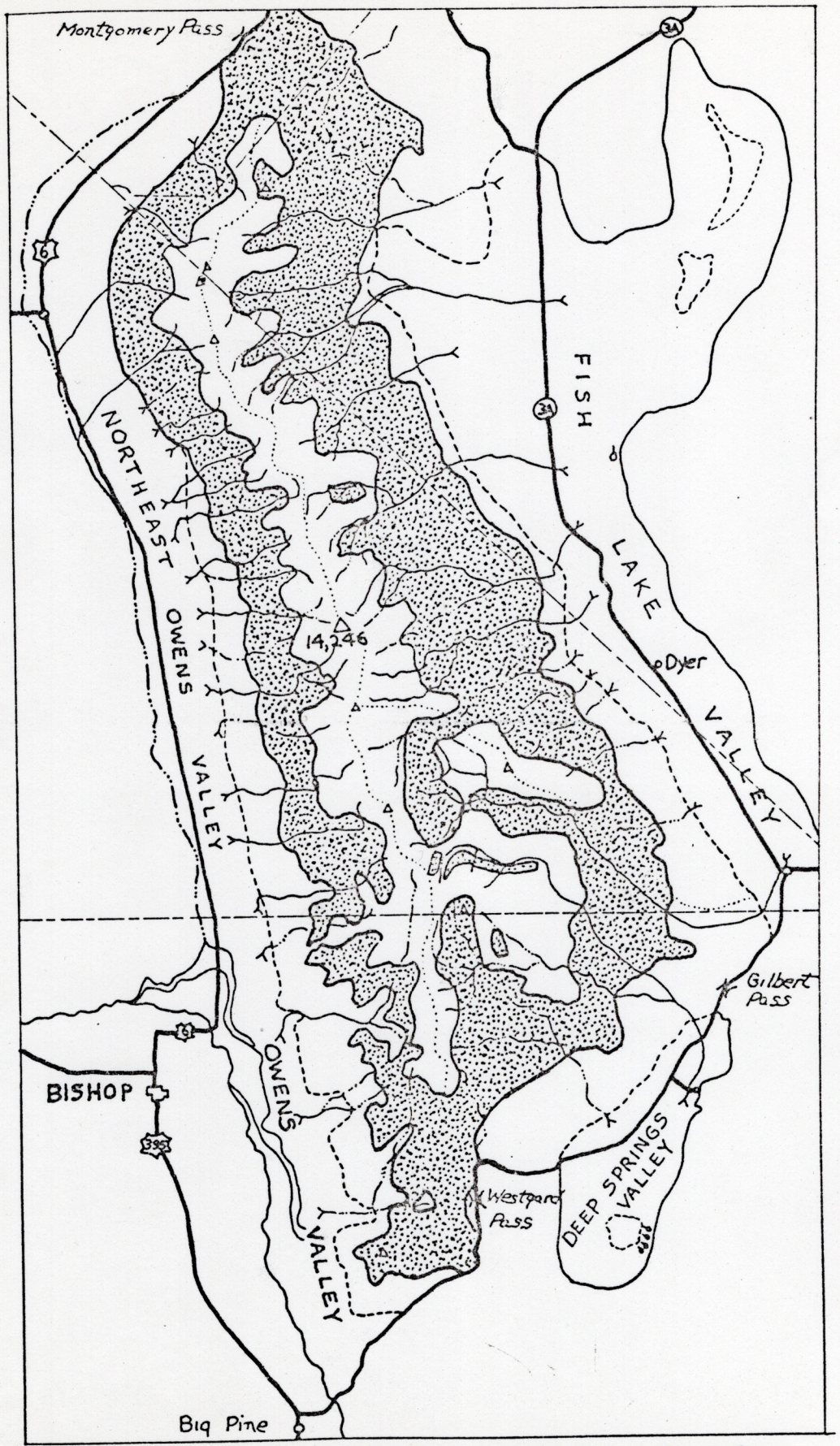

Fig. 85. Woodland and forest areas of the White Mountains. Stippled portion of map indicates both woodland of pinyon-juniper zone and forest of upper pine zone.

the upper pine belt.

Alpine Zone. Above 11,500'. (Table IX, p. 154.)

This zone is differentiated from the others by a total lack of trees. The most irregular interzonal boundary is that between the preceding zone and this one. Fluctuations of timberline and the frequent absence of timber fail to provide a clear line of demarcation.

Shrubs, particularly Artemisia arbuscula nova, Chrysothamnus viscidiflorus pumilus, Haplopappus Macronema, and Ribes cereum are found in this zone 1,000' to 1,500' higher than timberline. Herbs and grasses grow right up to the summit of White Mountain Peak at 14,246'.

Since a relatively large area of low relief, favorable for plant habitation, exists on the summit upland above timberline, the alpine herbaceous vegetation is extensive, covering broad expanses of coarsely weathered rock with a low mat-like growth. Most of the herbs are suffrutescent at base. Nearly all of the species in the alpine zone are found below timberline, although a few--Hulsea algida (Fig 85, p. 152), Polemonium chartaceum, and Ranunculus Escholtzii--are largely restricted to the area above timberline. A noteworthy species, abundant in this zone and the upper pine zone, is Trifolium monoense (Fig. 86, p. 155), a cespitose clover much prized as forage for sheep during the period from 1890 to 1910 when the summit upland was extensively grazed by sheep from the southern San Joaquin Valley in California.

Because of the lack of streams at high elevation, wet habitats are restricted to springs and seepages, with Carex spp. and the grass Deschampsia caespitosa important species. Much of the summit upland is moist throughout the summer from melting snow and summer rain, and some of the alpine zone has a light green turflike appearance from June to

TABLE IX

Characteristic Plants and Mammals
in the Alpine Zone

SHRUBS

Artemisia arbuscula nova
Chrysothamnus viscidiflorus pumilus
Haplopappus Macronema
H. suffruticosus
Leptodactyon pungens
Linanthus Nuttallii

HERBS

Androsace septentrionalis
subumbellatum
Antennaria rosea
Arenaria Kingii compacta
Calyptridium umbellatum (pussy paws)
Castilleja nana
Cerastium berrangium
Draba Breweri
D. oligosperma subsessilis
Erigeron compositus
E. vagus
Eriogonum Kennedyi
Gentiana tenella
Haplopappus apargioides
Hulsea algida
Ivesia lycopodioides scandularis
I. Shockleyi
Lewisia pygmaea
Mimulus Suksdorfii
Oxyria digyna
Oxytropis viscida
Pedicularis attolens (elephant heads)
Penstemon heterodoxus
Phlox Covillei
Podistera nevadensis
Polemonium chartaceum
Potentilla pseudosericea
Ranunculus Escholtzii
Sedum Rosea integrifolium
Trifolium monoense

GRASSES, RUSHES, and SEDGES

Agropyron Scribneri
Carex spp., esp. Helleri, subnigricans, vernacula
Festuca brachyphylla
Juncus balticus (rush)
J. Parryi
Koeleria cristata
Phleum alpinum
Poa incurva
P. rupicola
Sitanion Hystrix
Stipa pinetorum
Trisetum spicatum

MAMMALS

Citellus lateralis (golden-mantled ground squirrel)
Lepus townsendii (white-tailed jackrabbit)
Marmota flaviventris (marmot)
Ochotona princeps (pika)
Ovis canadensis (bighorn sheep)
Peromyscus maniculatus (deermouse)

September (Fig. 87, p. 155). Grasses, rushes, and sedges consitute a larger percentage of this flora than in the lower zones.

The relatively abundant vegetation above timberline supports a sizeable population of mammals. Although usually listed from other areas at much lower elevations, the golden-mantled ground squirrel (Citellus lateralis) is frequent to common in the alpine zone. Portions of the summit upland are honeycombed with its burrows. Undoubtedly, this squirrel's burrowing exerts important geomorphic influences by comminuting weathered rock and by providing access to sub-surface strata of snowmelt water and rainwater. Other commonly seen mammals in the alpine zone are the white-tailed jackrabbit (Lepus townsendii) in any open terrain and the marmot (Marmota flaviventris) in and near well-jointed rock outcrops.

Perhaps the most interesting mammal in the White Mountain area is the bighorn sheep (Ovis canadensis) (Fig. 88, p. 157). A population of about 40 bighorns resides in the alpine zone most of the year--occasionally being driven to lower elevations by heavy snow. At such times they usually descend to the interfluvial ridges of the west slope, since these areas are the first to become free of snow. Although they range throughout the summit upland, the favored habitat is the rugged topography immediately north of White Mountain Peak. It is generally assumed that White Mountain bighorns are of the race nelsoni, which ranges through southeastern California and southern Nevada. The relatively dark coat of some White Mountain sheep observed by the writer indicates a possible relationship with the race californiana resident in the southern Sierra Nevada.

Interzonal Species

Several plant species range through all of the zones. Examples are Juncus balticus, possibly better divided into two or more species,

and the grasses Koeleria cristata and Sitanion hystrix. The morphologic adaptations to a continuous climatic gradient from low to high elevation appear gradual. Such species offer much opportunity for study of genetics and ecological adaptation.

There are also several mammal species which are found in all zones. Most notable is the deermouse (Peromyscus maniculatus), which occupies a wide variety of habitats at all elevations, including the summit of White Mountain Peak. The metabolic and reproductive rates of these mice at different elevations and of the same mouse at varying altitudes have been the object of much scientific interest.

The mule deer (Odocoileus hemionus) may occur in any zone; bucks are often in the alpine zone during the summer and early fall. Predator species, like the bobcat (Lynx rufus), coyote (Canis latrans), and mountain lion (Felix concolor) may also occur in any zone. The coyote frequently hunts white-tailed jackrabbits or small rodents in the alpine zone in midwinter.

Introduced Species

By far the largest number of introduced plants in the White Mountain area is found in the desert shrub zone. The number rapidly diminishes in the pinyon-juniper zone and dwindles to none in the austere environment of the upper alpine zone. Probably the most troublesome weed in cultivated areas at present is bindweed (Convolvulus arvensis), deep-rooted and difficult to eradicate. The most successful invader of cleared or disturbed ground is Russian thistle (Salsola Kali tenuifolia). It occurs as high as 10,500' in the White Mountains. A common invader of somewhat alkaline places is Bassia hyssopifolia. During wet years there is abundant growth of cheat grass (Bromus tectorum) in the pinyon-juniper

zone. A few introduced plants, such as sweetclover (Melilotus albus) and filaree (Erodium cicutarium), provide some beneficial forage.

Wild horses may be encountered anywhere in the area, but are especially numerous in the Trail Canyon area in the northeastern sector of the White Mountains. They have adapted extremely well to the rugged terrain of that region and have resisted successfully many attempts to round them up or to exterminate them.

A number of animal introductions have been made intentionally for recreation or conservation. All the perennial streams in Fish Lake Valley have been planted with trout. The Owens River has been planted with bluegill, largemouth bass, smallmouth bass, and catfish, as well as trout. It is generally considered to be one of the premium trout streams in California. Within the White Mountains in 1946 a plant of Piute trout (Salmo clarkii seleniris), a race of cutthroat trout native to a small drainage area in Alpine County, California, was made in upper Cottonwood Creek (personal communication, California Department of Fish and Game). The purpose was to extend the range of this rare trout; but heavy fishing pressure on Cottonwood Creek makes the future of Piute trout there precarious. The chukar partridge (Alectoris graeca)was introduced as a game bird and now exists at all elevations in the area. In 1933 and 1934 a few survivors of a once large herd of tule elk (Cervus nannodes) were transplanted from the San Joaquin Valley to Owens Valley, with the hope of preserving the species from extinction. The herd has now built up to more than 300 individuals. The northern part of its range east of Owens River extends into the southwestern portion of the White Mountain area. The future of the elk is somewhat in doubt. Cattlemen complain of depredation and would like to see the number of elk sharply reduced or

the herd eliminated from Owens Valley. Occasional controlled hunts are held to cull surplus animals, but the optimum population is a matter of much controversy among stockmen, game managers, and conservationists.

CONCLUSION

"None other than this long brown land lays such a hold on the affections," wrote Mary Austin in tribute to "The Land of Little Rain" lying east of the Sierra Nevada along the California-Nevada border. A most interesting and diverse portion of this "land of little rain" is the White Mountain Range and its surrounding valleys, a region which combines features of both desert Great Basin and alpine Sierra Nevada.

The climate is arid to semi-arid, cold desert to cold steppe. At its base the aspect is desert--precipitation is 4" to 6" a year; at its summit, 10,000' higher, the aspect is alpine--precipitation is 15" to 20" a year; snowdrifts persist throughout the summer. The topography is one of massive scale and marked contrast. Flat valley floor and gently rolling summit upland are separated by steep slopes of 5,000' to 10,000'. The area offers superb illustrations of landforms resulting from faulting. Climatic and topographic diversity mean a great variety of plant and animal life.

Economic utilization of the region, as yet, has been slight. Mining of precious metals never approached the scale of important nearby areas, such as Tonopah and Goldfield. Current development of mercury deposits in the northeastern sector of the White Mountains may result in a major mining operation. In the past logging has been restricted to local needs, such as mine props and locomotive fuel for a narrow gauge railroad no longer in existence. The open stands, the lack of suitable species of trees, and the inaccessibility of the woodland and forest in the White Mountains do not indicate commercial logging in

the foreseeable future. Agriculture, primarily livestock and forage production, has been of some importance, chiefly at the foot of the mountains, but significant expansion in the near future is unlikely. Precipitation is too low for dry farming. The largest potential supply of water for irrigation, the Owens River, is controlled by the City of Los Angeles; other surface water is now fully developed. Further development of groundwater is possible, but total supply is limited. Other agricultural problems are a short growing season, soil susceptible to wind erosion, and the long distance from metropolitan markets.

No more than 5% of the region is in private ownership. The City of Los Angeles owns much of Owens Valley. Nearly all of the rest of the valley land is public domain, administered by the Bureau of Land Management. With the exception of a few mining patents, the White Mountain Range is a part of Inyo National Forest, administered by the United States Forest Service.

Since the establishment of the White Mountain Research Station in 1948, there has been an ever increasing interest in scientific research carried out in the White Mountains. The Station, operated since 1950 by the University of California, serves as a base for any research project in which a high altitude environment is desirable. Laboratories exist at Big Pine (3,985') in Owens Valley and at 10,150', 12,470', and 14,246' in the White Mountains; all but the highest are kept open the year around. The mountain laboratories are connected by an unpaved road from Westgard Pass to the summit of White Mountain Peak.

The bristlecone pine forest in the southern part of the Range has attracted a rapidly growing number of visitors, as publicity

concerning the age of the trees becomes widespread. In order to protect the trees, the Forest Service has withdrawn from entry for any use, including mining, most of the bristlecone area from Reed Flat to Sheep Mountain. Recreational development in the area thus far has included the construction of public campgrounds, the building of trails, and the maintenance of information personnel during the summer months. Previously, hunting had been the only significant recreational activity in the White Mountains. Eventually, the bristlecone area may become part of the National Park System.

BIBLIOGRAPHY

Abrams, L. and R.B. Ferris 1960. Illustrated Flora of the Pacific States; Washington, Oregon, and California. 4 Volumes, Stanford University Press, Stanford, California.

Anderson, G.H. 1937. Granitization, Albitization, and Related Phenomena in the Northern Inyo Range of California-Nevada. Bull. Geol. Soc. Amer., Vol. 48, pp. 1-74.

Austin, M. 1950. The Land of Little Rain. Houghton Mifflen Co., Boston, 132 pp.

Axelrod, D.I. 1940. The Pliocene Esmeralda Flora of West-Central Nevada. Jour. Wash. Acad. Sci., Vol. 30, No. 4, pp. 163-174.

Axelrod, D.I. and W.S. Ting 1960 Late Pliocene Floras East of the Sierra Nevada. Univ. of California Publ. in Geological Sciences, Vol. 39, No. 1, 118 pp.

Axelrod, D.I. 1962. Post-Pliocene Uplift of the Sierra Nevada, California. Bull. Geol. Soc. Amer., Vol. 73, pp. 183-198.

Bateman, P. 1962. Geology. In: Deepest Valley. Edited by Genny Schumacher, Sierra Club, San Francisco, pp. 100-122.

Beaty, C.B. 1960. Gradational Processes in the White Mountains of California and Nevada. Ph.D. Thesis, Univ. of California.

Benson, L. and R.A. Darrow 1944. A Manual of Southwestern Desert Trees and Shrubs. Univ. of Arizona Bull., Biol. Sci. Bull. No. 6, 409 pp.

Billings, W.D. 1949. The Shadscale Vegetation Zone of Nevada and Eastern California in Relation to Climate and Soils. Amer. Midl. Nat., Vol. 42, pp. 87-109.

----------. 1954. Temperature Inversions in the Pinyon-Juniper Zone of a Nevada Mountain Range. Butler Univ. Bot. Stud., Vol. 11, pp. 112-118.

Blackwelder, E. 1928. Mudflow as a Geologic Agent in Semi-arid Mountains. Bull. Geol. Soc. Amer., Vol. 39, pp. 465-483.

----------. 1931. Pleistocene Glaciation in the Sierra Nevada and Basin Ranges. Bull. Geol. Soc. Amer., Vol. 42, pp. 865-922.

----------. 1934. Supplementary Notes on Pleistocene Glaciation in the Great Basin. Jour. Wash. Acad. of Sci., Vol. 24, 1934, pp. 217-222.

----------. 1954a. Geomorphic Processes in the Desert. In: Geology of Southern California, State of California, Dept. of Nat. Resources, Div. of Mines, pp. 11-19.

Blackwelder, E. 1954b. Pleistocene Lakes and Drainage in the Mojave Region, Southern California. In: Geology of Southern California, State of California, Dept. of Nat. Resources, Div. of Mines, pp. 35-40.

Blane, R.P. 1958. Geology of the Deep Spring Valley Area. M.A. Thesis, Univ. of Calif. at Los Angeles.

Burt, W.H. and R.P. Grossenheider 1952. A Field Guide to the Mammals. Houghton Mifflin Co., Boston, 200 pp.

Clokey, I.W. 1951. Flora of the Charleston Mountains, Clark County, Nevada. Univ. of Calif. Publ. in Botany, Vol. 24, 274 pp.

Daubenmire, R.F. 1954. Alpine Timberlines in the Americas and Their Interpretation. Butler Univ. Bot. Studies, Vol. 11, pp. 119-136.

----------. 1959. Plants and Environment. John Wiley and Sons, New York, 422 pp.

Dayton, W.A. 1940. Range Plant Handbook. Forest Service, U.S. Dept. of Agric., U.S. Govt. Printing Office, Washington.

D'Ooge, C.L. 1955. Continentality in the Western U.S. Bull. Amer. Meteorological Society, Vol. 36, No. 4, pp. 175-177.

Eakin, T.E. and H.G. Mason 1950. Preliminary Report on Ground Water in Fish Lake Valley, Nevada and California. State of Nevada, Office of the State Engineer, Water Resources Bull. No. 11, 37 pp.

Emerson, D.O. 1959. Granitic Rocks of the Northern Portion of the Inyo Batholith. Ph.D. Thesis, Penn. State Univ.

Gilbert, C.M. 1941. Late Tertiary Geology Southeast of Mono Lake, California. Bull. Geol. Soc. Amer., Vol. 52, pp. 781-816.

Hall, E.R. 1946. Mammals of Nevada. Univ. of Calif. Press, Berkeley, 710 pp.

Hitchcock, A.S. 1951. Manual of the Grasses of the United States. Second Edition Revised by A. Chase. U.S. Dept. of Agric., Misc. Publ. 200, U.S. Govt. Printing Office, Washington, 1051 pp.

Holmboe, J. and H. Klieforth 1954. Final Report: Sierra Wave Project. Contract NO. AF 19 (122)-263, Dept. of Meteorology, Univ. of Calif. Los Angeles.

Holmgren, A.H. 1942. Handbook of the Vascular Plants of Northeastern Nevada. Cooperative Study by Graying Service, U.S. Dept. of Interior, and Utah State Agric. Coll. and Exper. Sta., 214 pp.

Hopper, R.H. 1947. Geologic Section from the Sierra Nevada to Death Valley, California. Bull. Geol. Soc. Amer., Vol. 58, pp. 393-432.

Hubbs, C.B. and R.R. Miller 1948. The Great Basin: The Zoological Evidence. Univ. of Utah, Biological Series, Vol. 10, pp. 17-166.

Kesseli, J.E. 1938. Pleistocene Glaciation in the Valleys Between Lundy Conyon and Rock Creek, Eastern Slope of the Sierra Nevada, California. Ph.D. Thesis, Univ. of California, Berkeley.

----------. 1941. Rock Streams in the Sierra Nevada, California. Geog. Rev., Vol. 31, pp. 203-227.

Kesseli, J.E. and C.B. Beaty 1959. Desert Flood Conditions in the White Mountains of California and Nevada. Quartermaster Research and Engineering Command, U.S. Army, Technical Report No. EP-108, Natick, Mass., 112 pp.

Matthes, F.E. 1934. Albation of Snowfields at High Altitudes by Radiant Solar Heat. Trans., Amer. Geophysical Union, Part 2, 1934, pp. 380-385.

----------. 1950a. (F. Fryxell, Editor) The Incomparable Valley, A Geologic Interpretation of the Yosemite. Univ. of Calif. Press, Berkeley, 160 pp.

----------. 1950b. (F. Fryxell, Editor) Sequoia National Park, A Geological Album. Univ. of Calif. Press, Berkeley, 136 pp.

----------. 1960. Reconnaissance of the Geomorphology and Glacial Geology of the San Joaquin Basin, Sierra Nevada, California. U.S. Geol. Surv., Prof. Paper No. 329, 62 pp.

McKee, E.H. 1961. The Stratigraphy and Structure of a Portion of the Magruder Mountain-Soldier Pass Quadrangles, California-Nevada. Ph.D. Thesis, Univ. of California.

McMinn, H.E. 1951. An Illustrated Manual of California Shrubs. Univ. of Calif. Press, Berkeley, 663 pp.

Miller, Wm.J. 1928. Geology of Deep Spring Valley, California. Jour. Geology, Vol. 36, No. 6, pp. 510-525.

Munz, P.A. and D.D. Keck 1959. A California Flora. Univ. of Calif. Press, Berkeley, 1681 pp.

Nelson, C.A. 1962. Lower Cambrian-Pre-Cambrian Succession, White-Inyo Mountains, California. Bull. Geol. Soc. Amer., Vol. 73, pp. 139-144.

Nolan, T.B. 1943. The Basin and Range Province in Utah, Nevada, and California. U.S. Geol. Surv., Prof. Paper No. 197-D, pp. 141-196.

Oosting, H.J. 1956. The Study of Plant Communities, 2nd Edition. W.H. Freeman and Co, San Francisco, 440 pp.

Palmer, R.S. 1954. The Mammal Guide. Doubleday Inc., Garden City, N.J., 384 pp.

Perry, L.J. 1954. Geology of the East-Central Portion of the Blanco Mountain Quadrangle, Inyo Co., California. M.A. Thesis, Univ. of Calif. at Los Angeles.

Pittman, E.D. 1958. Geology of the North Portion of the Blanco Mountain Quadrangle, Inyo Co., Calif. M.A. Thesis, Univ. of Calif. at Los Angeles.

Putnam, W.C. 1960. Origin of Rock Creek and Owens River Gorges, Mono County, California. Univ. of Calif. Publ. in Geol. Sciences, Vol. 34, No. 5, pp. 221-280.

Russell, R.J. 1933. Alpine Land Forms of Western United States. Bull. Geol. Soc. Amer., Vol. 44, pp. 927-950.

Schulman, E. 1956. Dendroclimatic Changes in Semi-arid America. Univ. of Arizona Press, Tucson, 142 pp.

----------. 1958. Bristlecone Pine, Oldest Known Living Thing. Nat. Geog., Vol. 103, No. 3, pp. 354-372.

Scorer, R.S. 1961. Lee Waves in the Atmosphere. Sci. Amer., Vol. 204, pp. 124-134.

Sharp, R.P. 1938. Pleistocene Glaciation in the Ruby-East Humboldt Range, Northeastern Nevada. Jour. of Geomorphology, Vol. 1, pp. 296-323.

----------. 1960. Pleistocene Glaciation in the Trinity Alps of Northern California. Amer. Jour. of Sci., Vol. 258, pp. 305-340.

Sharpe, C.F.S. 1938. Landslides and Related Phenomena. Columbia University Press, New York, 137 pp.

Steward, J.H. 1938. Basin-Plateau Aboriginal Sociopolitical Groups. Smithsonian Inst., Bur. of Amer. Ethnology, Bull. 120, 346 pp.

Summer, L. and J.S. Dixon 1953. Birds and Mammals of the Sierra Nevada. Univ. of Calif. Press, Berkeley, 484 pp.

Thompson, W.F. 1960-61. The Shape of New England Mountains. Appalachia, Vol. 33, pp. 145-159, 316-335, 458-478.

Tidestrom, I. 1925. Flora of Utah and Nevada. U.S. Nat. Mus., Nat. Herbarium, Contributions, Vol. 25.

Turner, H.W. 1900. The Esmeralda Formation, a Fresh Water Lake Deposit. U.S.G.S., 21st Annual Report, Pt. 2, pp. 191-208.

Wahrhaftig, C. and A. Cox 1959. Rock Glaciers in the Alaska Range. Bull. Geol. Soc. Amer., Vol. 70, pp. 383-436.

Washburn, A.L. 1956. Classification of Patterned Ground and Review of Suggested Origins. Bull. Geol. Soc. Amer., Vol., 67, pp. 823-866.

Watson, E.B. and R.E. Storie 1928. Soil Survey, Bishop Area, California. U.S. Dept. of Agriculture, Bur. of Chemistry and Soils, in Cooperation with Univ. of California Agric. Exper. Sta., Series 1924, No. 3, pp. 63-95.

Went, F.W. 1955. The Ecology of Desert Plants. Sci. Amer., Vol. 192, No. 4, pp. 68-75.

BIOLOGY S 11

THOUGHTS ON A LABORATORY

A laboratory is a place where we gain first-hand acquaintance with materials and with methods of science

A laboratory in biology is a place where we go exploring living plants and animals; their structures and their functions; their movements, their growth, their activities

-- a place where we study living organisms by observational techniques of science
-- a place where we record and measure accurately
-- a place where we learn to recognize problem situations and then plan and execute tests to determine possible explanations

A laboratory is set up to help us develop attitudes--because science is an attitude

A laboratory is a place where we depend on ourselves for motivation and direction;
-- a place where we find that something may be true because it falls in line with our own experiences

A laboratory is a place where you may explore ideas, materials, techniques in an environment where emphasis is placed on "the spirit of inquiry" --your own curiosity.

A laboratory is a place where as you explore you may have freedom with responsibility. But what then is your responsibility in science?

A laboratory is a place where independence of thought is essential; where originiality is an asset provided it is directed toward exploration and the searching by you for possible solutions to questions you raise.

A laboratory is a place where an error is a rung in the ladder of understanding.

A laboratory is a place where we can use the ideas of the lecture or of the book, or of the reference literature in a creative activity of helping ourselves develop understandings and build our own concepts of life and life processes

A laboratory is a place where you are challenged to try!

A laboratory is a sacred place where the greatest of human achievements have been and are being accomplished--that of using ideas to build greater concepts and understanding of ourselves in relation to all other living organisms.

A laboratory is a place where we, your instructors, will be present to provide you with opportunities and to channel your activities. NEVER expect us to tell you what to see, what to think, what to memorize, or what to study! We sincerely hope that you will make the choices from the materials and opportunities that we provide to gain lasting values from exploration and discovery for yourselves.

GOOD LUCK in this GREAT UNDERTAKING

BIOLOGY S 11
Dr. Weston
Lecture # 3:1

NSF Summer Program in Biology

I. The Nature of Life and possibilities to explain its origin:

a. we now have evidence that elements and compounds are present on other planets than earth

some of these elements and compounds are supposed to have been those present on earth in its early history as a solid

nitrogen
hydrogen
methane
ammonia

b. suppose that the primordial life was built of such elements and compounds, what would have been the energy source for synthesis of life?

cosmic rays
shortwave light (ultra violet region of the spectrum)
electric spark

c. scientific experiments by Urey and Miller subjected solutions with these elements and compounds to prolonged electrical discharge

amino acids were formed
formic series were also formed
acetic series were also formed

d. synthesis of protein-materials have been shown to take place without enzymes

without enzymes the reaction is slower(in time)

e. the fossil history shows that early life was present in its now-known form in the Cambrian period of time- in the Paleozoic Era.

early forms of life were thought to have originated in the Proterozoic Era that preceded the Paleozoic.

Barghoorn at Harvard - a paleobotanist examined the charts of Ontario (rock of Proterozoic origin); dissolved its silica and found microscopic evidence of relatives of the filamentous blue-green algae and the sheathed bacteria.

Analysis of this gives evidence for 8 amino acids (analysis by chemical tests)

Although it is amazing that such records can be found, remember that the earth's atmosphere in the Proterozoic was a reducing one--not an oxidizing one. With no oxygen present, there could have been no bacteria that cause decay--hence the early proteinaceous remains can be found.

II. A dilema arises to confront science now, in the face of this evidence.

a. The problem: Did life originate by spontaneous generation? or Does life always come from preexisting life?

Miss Enid Larson's Collection of "Scientific American" Articles in Biology
(These are available from reserve shelf at Loan Desk of Campus Library; they may be read in Library Reading Room or taken out over night or over weekends)

No.	Title
	GENERAL ARTICLES
1	The Origin of Life
2	Protein
3	How Protein is Made
4	Nucleic Acids and Proteins
	VERTEBRATES
5	How Fishes Swim
6	How Reptiles Regulate Their Body Temperatures
7	Reptiles at Home
8	How A Rattlesmake Strikes
9	Snakebite
10	The End of the Moose
11	Penguins
12	Incubator Birds
13	Salt Glands
14	Evolution of Birds
15	The Language of Birds
16	The Languageof Crows
17	Bats
18	Camel Physiology
20	Too Many Deer
21	Populations of House Mice
22	Love in Infant Monkeys
23	The Enduring Indian
24	The Idea of Man's Antiquita
25	Group Conflict
	INVERTEBRATES
26	Hydra
27	The Edible Snail
28	Spider Webs
29	Living Insecticides
30	The Fire Ant
31	The Leap of the Grasshopper
32	Metamorphosis, Polymorphisis, Differentiation
33	Insects and Plants
34	Weed Control by Insects
35	Corn Borers
36	The Juvenile H ormone
37	Insects and the Length of Day
38	The Flight of Locusts
	PLANTS
39	Germination
40	(see next page)

No.	Title
44	Photosynthesis
45	Plants Circulatory System
46	Growth of Mushrooms
	MICROBIOLOGY
47	Second Thoughts on the Germ Theory
48	Rabbit Plague
49	Antibiotics--Plant Diseases
50	The Blight of Potatoes
51	Gibbirella - A Fungus
52	Beer
53	Social Amoeba
54	Molds and Men
55	Bacteria
56	Tuberculosis
57	Rickettsiae
58	Bacteria - Transduction
59	Bacteria - Staphylococcus
60	Enterococcus
	ENZYMES AND CELLS
61	H ow Antibodies are Made
62	H eat and Lye
63	The Enzymes Substrate Complex
64	The Organizer - Differentiation of Cells
65	Fertilization - Zygotes
66	Fertilization and Antibodies
	BLOOD AND CIRCULATION
67	Heart
68	Open Heart Surgery
69	The Micro-Circulation of Blood
70	The Wonderful Net
71	Blood
72	The Red Blood Cell
	HORMONES
73	The Action of Insulin
74	Hormones
75	Progesterone
	PHYSIOLOGICAL PROBLEMS
76	Barriers in the Brain
77	Biological Oxidation
78	(see next page)

No.	Title
83	The Chemical Senses
84	Nerve Impulses and the Squid
85	The Contraction of Muscle
	RADIATION BIOLOGY
86	Radiation Strontium
87	Isotopes in Soil Research
88	Ionization Radiation and the Citizen
89	Ionization Radiation
90	Ionization Radiation and Evolution
	STRUCTURE
91	The Ear
	BIOGRAPHY
92	Francis Galton
93	Helmhaltz
94	Joseph Henry
95	Michael Faraday
96	Issaac Newton
97	Charles Lyell
98	Darwinism
99	Alfred Wallace
100	Albert Einstein
	MISCELLANEOUS
101	Ecology--Sand Dune Association
102	The Ecosphere
103	Water
104	Water
105	Alkaloids
106	Nuclear Explosives
107	Carbon Dioxide and Climate
108	Worm Autobiographies
109	Poisons
110	Microscope--Flying Spot
111	Atomic Fission
112	Mars
113	Self Reproducing Machines
114	High Speed Research Machines
115	The Invention of the Electric Light

No.	Title
40	Wheat H ybridization
41	Plant Movements
42	What Makes Leaves Fall
43	Flowering Process
78	The Synthesis of Milk
79	Body
80	The Synthesis of Fat
81	Tissues from Dissociated Cells
82	Wound Shock

Miss Enid Larson's Collection of "Scientific American" Articles in Biology
(These are available from reserve shelf at Loan Desk of Campus Library; they may be read in Library Reading Room or taken out over night or over weekends)

No.	Title
	GENERAL ARTICLES
1	The Origin of Life
2	Protein
3	How Protein is Made
4	Nucleic Acids and Proteins
	VERTEBRATES
5	How Fishes Swim
6	How Reptiles Regulate Their Body Temperatures
7	Reptiles at Home
8	How A Rattlesmake Strikes
9	Snakebite
10	The End of the Moose
11	Penguins
12	Incubator Birds
13	Salt Glands
14	Evolution of Birds
15	The Language of Birds
16	The Languageof Crows
17	Bats
18	Camel Physiology
20	Too Many Deer
21	Populations of House Mice
22	Love in Infant Monkeys
23	The Enduring Indian
24	The Idea of Man's Antiquita
25	Group Conflict
	INVERTEBRATES
26	Hydra
27	The Edible Snail
28	Spider Webs
29	Living Insecticides
30	The Fire Ant
31	The Leap of the Grasshopper
32	Metamorphosis, Polymorphisis, Differentiation
33	Insects and Plants
34	Weed Control by Insects
35	Corn Borers
36	The Juvenile H ormone
37	Insects and the Length of Day
38	The Flight of Locusts
	PLANTS
39	Germination
40	(see next page)

No.	Title
44	Photosynthesis
45	Plants Circulatory System
46	Growth of Mushrooms
	MICROBIOLOGY
47	Second Thoughts on the Germ Theory
48	Rabbit Plague
49	Antibiotics--Plant Diseases
50	The Blight of Potatoes
51	Gibbirella - A Fungus
52	Beer
53	Social Amoeba
54	Molds and Men
55	Bacteria
56	Tuberculosis
57	Rickettsiae
58	Bacteria - Transduction
59	Bacteria - Staphylococcus
60	Enterococcus
	ENZYMES AND CELLS
61	H ow Antibodies are Made
62	H eat and Lye
63	The Enzymes Substrate Complex
64	The Organizer - Differentiation of Cells
65	Fertilization - Zygotes
66	Fertilization and Antibodies
	BLOOD AND CIRCULATION
67	Heart
68	Open Heart Surgery
69	The Micro-Circulation of Blood
70	The Wonderful Net
71	Blood
72	The Red Blood Cell
	HORMONES
73	The Action of Insulin
74	Hormones
75	Progesterone
	PHYSIOLOGICAL PROBLEMS
76	Barriers in the Brain
77	Biological Oxidation
78	(see next page)